BIOMASS YIELD AND SILAGE CHARACTERISTICS OF ELEPHANTGRASS (Pennisetum
purpureum SCHUM.) AS AFFECTED BY HARVEST FREQUENCY AND GENOTYPE

BY

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Dedicated to my parents
Mark and Mozelle Woodard

ACKNOWLEDGMENTS

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Abstract of Dissertation Presented to the Graduate School
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Major Department: Agronomy

Elephantgrass (Pennisetum purpureum Schum.) is being evaluated in
Florida as a biomass energy crop and a forage for ruminants. In a 2-year
study conducted on a dry, infertile site and under the subtropical
conditions near Gainesville, the response of this forage to three harvest
frequency regimes was measured. Genotypes evaluated were four "tall"
elephantgrasses (PI 300086, Merkeron, N-43, and N-51), a "dwarf"
elephantgrass ('Mott'), a "semi-dwarf" Pennisetum glaucum x P. purpureum
hybrid (Selection No. 3), and a "tall" Saccharum species of energycane
(L79-1002). To determine if these grasses could be stored as silage, the
fresh chopped plant materials of PI 300086, Merkeron, Mott, and L79-1002
were hand-packed into 20-liter plastic containers lined with two 4-mil
plastic bags.

Mean dry biomass yields for the four tall elephantgrasses during
1986-87 were 27, 24, and 18 Mg ha^{-1} yr^{-1} for one, two, and three harvests
yr^{-1}, respectively. In vitro organic matter digestibilities (IVOMD) were
40, 49, and 55% while crude protein (CP) contents were 4.0, 5.8, and 7.9%

(dry basis), respectively. Ash-free neutral detergent fiber (NDF) contents were 81, 76, and 74% (dry basis). Predicted methane production ha^{-1} yr^{-1} for PI 300086 was similar for all harvest treatments.

For Mott dwarf elephantgrass, 2-year mean dry biomass yields were 13, 12, and 11 Mg ha^{-1} yr^{-1} for one, two, and three harvests yr^{-1}, respectively. Mean IVOMDs were 40, 54, and 57% while CP contents were 5.3, 7.1, and 9.6%, respectively. Two-year NDF means were 77, 73, and 70%.

Merkeron, N-43, N-51, Mott, and L79-1002 survived the experimental conditions. Genotype PI 300086 survived during 1986-87; however, major stand losses occurred over the 1987-88 winter following the second growing season in plots harvested multiple times. An almost complete loss of stand occurred in Selection No. 3 plots.

Mean pH values ranged from 3.8 to 4.0 for the tall elephantgrass silages made from plants harvested at the different frequencies. The highest pH values were obtained from silages made from immature Mott plants harvested three times yr^{-1} (2-year mean was 4.3). Water soluble carbohydrate contents of fresh elephantgrass forages (range: 2.6 to 8.4%, dry basis) tended to increase with more frequent harvesting. Buffering capacities of fresh PI 300086 and L79-1002 biomass were low and also increased with more frequent harvesting. Lactic acid was the major end-product of fermentation in most silages with the exception of those made from immature Mott and L79-1002 plants where lactic and acetic acids were both major components. Butyric acid levels were negligible in all silages. Dry matter recoveries for all silages ranged from 84 to 98%. Silage IVOMDs were mainly dependent on the IVOMDs of the standing forages at the time of harvest.

CHAPTER 1
INTRODUCTION

Elephantgrass or napiergrass (Pennisetum purpureum Schum.) is a
perennial erect bunchgrass that was first cultivated in South Africa
around 1910 (Van Zyl, 1970). Since then elephantgrass research has
been conducted throughout the tropics and warmer subtropics. The
purpose of most of the past research was to evaluate this grass as a
forage for ruminants.

In recent times new objectives have surfaced which focus on
elephantgrass as a renewable biomass energy source. The Arab-OPEC oil
embargo of 1973-74, which caused widespread fuel shortages in the USA,
was the initial motivating force behind the creation of biomass energy
research programs in many parts of this country.

In Florida, energy programs were implemented in the early 1980s
to evaluate different plant species for biomass production. Of over
150 field tested species, elephantgrass was chosen by agronomists at
the University of Florida as one of three plant species for intensive
evaluation (Smith, 1984). Elephantgrass was selected because of its
ability to produce large amounts of plant biomass per unit land area.
Record dry matter yields have been reported at two locations in the
tropics that exceed 80 Mg ha^{-1} yr^{-1} (Watkins and Severen, 1951;
Vicente-Chandler et al., 1959). Other desirable attributes include a
positive yield response to very high rates of nitrogen fertilization,
the perennial nature of the plant, and the tolerance to severe drought

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stress with subsequent compensatory growth when favorable growing conditions prevail.

Other developments in recent years have renewed interest in elephantgrass. The development of "dwarf" strains of elephantgrass by researchers at Tifton, Georgia, has increased its potential in ruminant animal production. Research by Boddorff and Ocumpaugh (1986) has shown dwarf genotypes to be superior in overall plant quality to that of "tall" Pennisetum hybrids. Furthermore, over several years forage agronomists at Gainesville have consistently reported average daily liveweight gains of one kg from steers grazing 'Mott' dwarf elephantgrass for prolonged summer-fall periods ranging from 126 to 177 days (Mott and Ocumpaugh, 1984; Sollenberger et al., 1988). Also, with improvements in mechanical forage harvesters, the highly productive tall genotypes can be more effectively harvested as greenchop or silage.

The following research was co-funded by the Gas Research Institute, Chicago, Illinois, and the Institute of Food and Agricultural Sciences, Gainesville, Florida. It consisted of an elephantgrass study that was conducted over two growing seasons on an infertile, dry location near Gainesville, Florida, where conditions may be classified as the colder subtropics. The primary objectives were to measure the effects of harvest frequency and genotype on biomass yield, forage quality, and stand persistence and to determine if elephantgrass could be successfully stored by ensiling.

CHAPTER 2
BIOMASS YIELD AND QUALITY CHARACTERISTICS OF ELEPHANTGRASS
AS AFFECTED BY HARVEST FREQUENCY AND GENOTYPE

Introduction

Elephantgrass is well known throughout much of the wet tropics for its prolific growth habit and usage as a forage for livestock. Presently, this C-4 grass is being intensively evaluated by agronomists in Florida as a renewable biomass source for methane production (Prine et al., 1988). Before elephantgrass can become a viable biomass source, however, more must be known about the performance of existing genotypes under different cultural conditions, particularly in the colder subtropical climate of North Central Florida.

Two factors that strongly affect elephantgrass performance are harvest frequency and genotype. Mislevy et al. (1986) reported dry biomass yields of 52.2 and 17.0 Mg ha^{-1} yr^{-1} for PI 300086 elephantgrass when harvested one and two times per season, respectively, at Ona, Florida. At Gainesville, Florida, Calhoun and Prine (1985) showed a curvilinear increase in annual biomass yield of PI 300086 elephantgrass with increased time between harvests (6, 8, 12, and 24 weeks). They also noted that plants growing under the 24-week harvest interval regime were more winter-hardy than those growing under the other three shorter intervals. Also working with PI 300086 elephantgrass at Gainesville, Shiralipour and Smith (1985)

reported declining methane yield per volatile solid (VS), with advancing plant maturity. For plant ages 75, 150, and 315 days, they obtained methane yields of 0.38, 0.30, and 0.25 standard m^3 kg^{-1} VS. In Puerto Rico, Vicente-Chandler et al. (1959) obtained dramatic increases in annual biomass yields and declining crude protein contents by increasing the length of harvest interval (40-, 60-, and 90-day intervals). Arroyo-Aguilú and Oporta-Téllez (1980) observed diminishing crude protein and increasing neutral detergent fiber levels in Merker elephantgrass with advancing plant maturity. In Malaysia, Wong and Sharudin (1986) reported in vitro dry matter digestibility values of 56, 50, and 44% for elephantgrass forage harvested at 4-, 8-, and 12-week intervals. Vélez-Santiago and Arroyo-Aguilú (1981) working with seven elephantgrass genotypes reported declining crude protein levels and increasing biomass yields with decreasing harvest frequency. Although all genotypes responded similarly to the effect of harvest frequency, they observed differences among genotypes in biomass yield, crude protein, and neutral detergent fiber concentrations. At Gainesville, Prine and Woodard (1986) evaluated several tall elephantgrass genotypes under full-season growth. Differences in biomass yield, lodging rate, and winter survival were observed among genotypes. The genotype PI 300086 often produced the highest biomass yield and was lodge resistant. It tended, however, to winterkill. Other high-yielding genotypes including Merkeron, N-51, N-43, and N-13 were much more cold tolerant.

The purpose of the following study was to measure the effects of harvest frequency and genotype on biomass yield, forage quality, and

winter survival in the colder subtropical area of Gainesville, Florida.

Materials and Methods

An elephantgrass biomass study was conducted over two growing seasons (1986-87) at the Green Acres University of Florida Research Farm approximately 20 km northwest of Gainesville, Florida. The soil at the site was a well-drained Arredondo fine sand (loamy, siliceous, hyperthermic, Grossarenic Paleudults). Soil organic matter contents ranged from 1.0 to 1.5%.

Weekly temperature, precipitation, and solar radiation data for Gainesville are shown in Fig. 1 for 1986 and Fig. 2 for 1987. The estimated dates of first and last freeze occurrence (50% probability) for the area are 28 November and 2 March, respectively (Bradley, 1983).

A factorial experiment with a split-plot design was planted in December 1985, using mature stem cuttings that were horizontally planted in a furrow. Main plots consisted of harvesting elephantgrass one, two, and three times per season while subplots were used to compare different genotypes including four "tall" elephantgrasses (PI 300086, Merkeron, N-51, and N-43). Also included was a tall-growing energycane (L79-1002) which is a cross between a commercial sugarcane variety (CP 52-68) and a wild Saccharum species (Tianan 96) from Argentina that was made in Louisiana (Giamalva et al., 1984). The four tall elephantgrasses were previously collected in 1980. They were among 40 genotypes that were selected as entries in an elephantgrass observation nursery which was

°C **AVERAGE WEEKLY TEMPERATURE**

mm **WEEKLY TOTAL PRECIPITATION**

ANNUAL TOTAL 1329

MJ/WEEK **AVERAGE WEEKLY SOLAR RADIATION**

ANNUAL TOTAL 6310
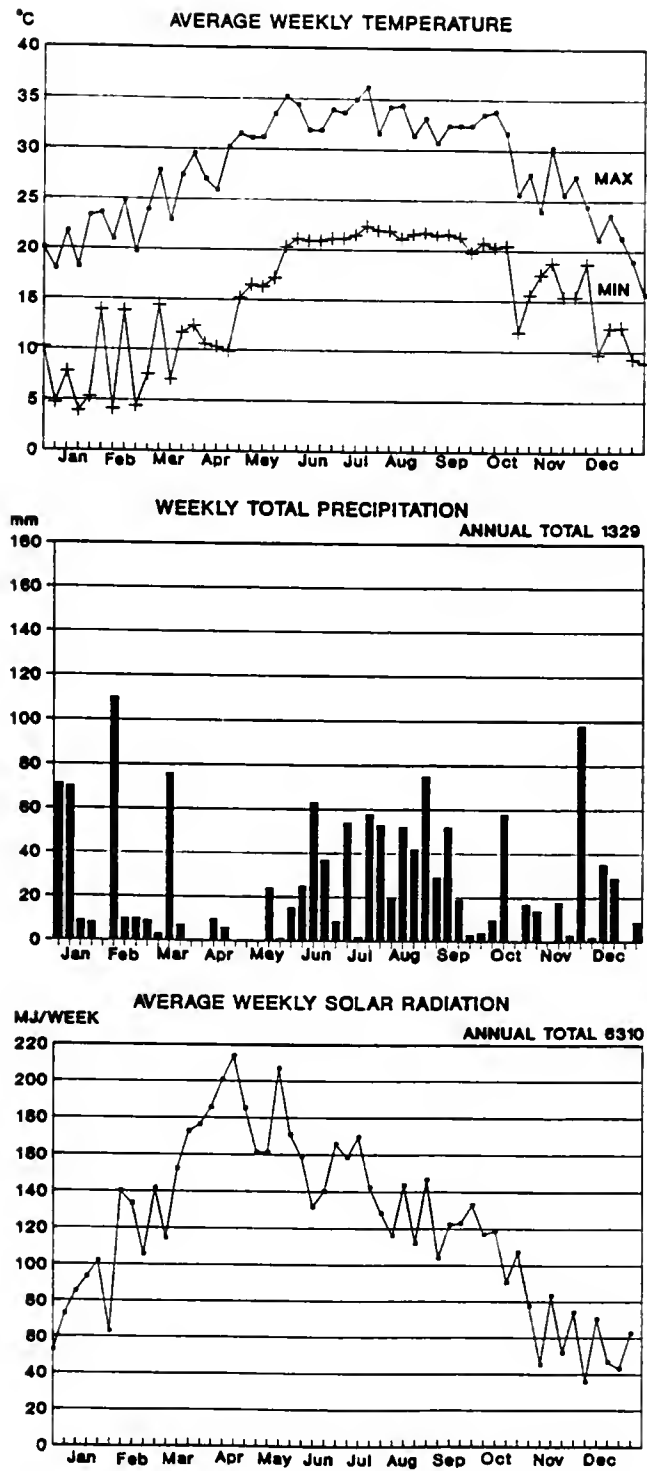
Fig. 1. Climatological data at Gainesville, Florida, for 1986.
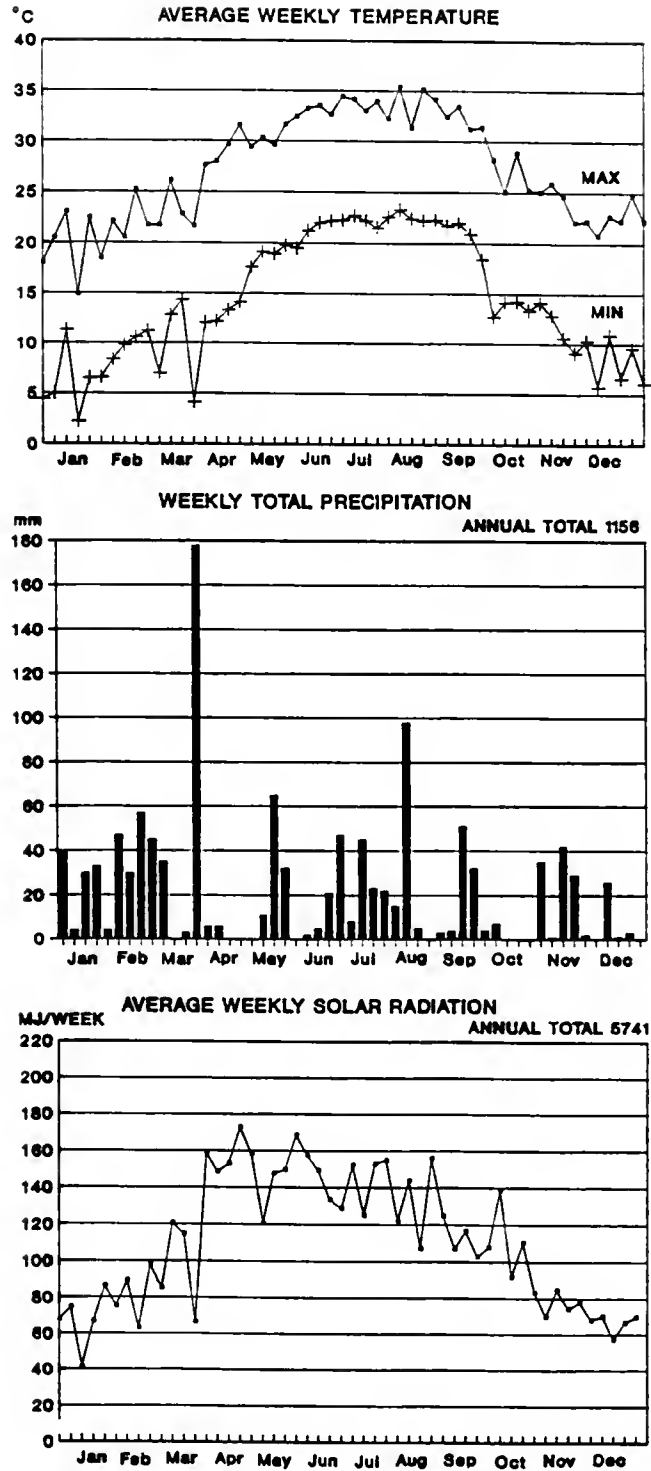
Fig. 2. Climatological data at Gainesville, Florida, for 1987.

planted in Gainesville that year. The original planting materials of
PI 300086 elephantgrass were collected at the USDA SCS Plant Materials
Center at Brooksville, Florida. Merkeron, N-51, and N-43 were
collected from the Georgia Coastal Plain Station at Tifton. The
genotype N-51 had been growing on the station as an escape for over 35
years (Prine et al., 1988). Merkeron is a tall hybrid that resulted
from a dwarf x tall elephantgrass cross made by G. W. Burton in 1941
(Hanna, 1986). In the present study the four tall elephantgrasses and
the energycane were grown together at one location.

A dwarf elephantgrass ('Mott') and a semi-dwarf _Pennisetum_ hybrid
[Selection No. 3 (_Pennisetum glaucum_ (L.) R. Br. x _Pennisetum_
purpureum Schum.)] were planted about 60 m away at another location
under the same split-plot design. Mott (formerly N-75) was named in
honor of the late Dr. Gerald O. Mott, Professor of Agronomy at the
University of Florida, who along with Dr. W. R. Ocumpaugh and their
students conducted the initial research that showed this dwarf strain
to possess unusually high forage quality (Sollenberger et al., 1988).
Mott was selected by W. W. Hanna in 1977 from among a selfed progeny
of Merkeron elephantgrass (Hanna, 1986). Selection No. 3 is a sterile
interspecific hybrid from a cross between Mott elephantgrass as the
male parent and 23DA dwarf pearlmillet as the female parent (Schank
and Dunavin, 1988).

All treatment combinations at both locations were completely
randomized in four blocks. A plot consisted of five rows. Plot row
length was 8 m while between-row width was 0.9 m. To avoid

competition between harvest frequencies and to facilitate mechanical harvesting, there were 1.8 and 2.7 m alleys separating main plots.

In the early spring of 1986, clump pieces were transplanted into the plots where plants failed to emerge. The plots were then irrigated three times during April and May to ensure an almost complete stand. This was the only irrigation the plots received during the entire study.

All plots received 336 kg N ha^{-1} yr^{-1} in a 4-1-2 ratio with P_2O_5 and K_2O. Plots harvested one time yr^{-1} received the total annual rate of fertilizer in a single spring application. The annual rate was split into two equal spring and summer applications for plots harvested two times whereas plots harvested three times received three equal spring, summer, and early fall applications.

During both years the harvest period for main plots cut one time per season was the third week of November. Plots cut two times were harvested in the first week of August and the third week of November. Plots cut three times were harvested in the first weeks of July and September and the fourth week of November.

A 6-m portion of the center row was harvested at a 10- to 15-cm cutting height from each plot to determine dry biomass yield. The tall grasses were mechanically harvested with a John Deere model 3940 forage harvester (Deere and Co., Moline, IL). Short grasses could not be effectively harvested with the forage harvester. They were cut down with a Stihl model FS 96 brushcutter (Stihl Inc., Virginia Beach, VA) and then chopped using the forage harvester. Subsamples weighing approximately 1.5 kg were collected from the fresh chopped biomass and

air-dried at 60°C. After drying, the subsamples were taken
individually from the dryer and weighed immediately to compute dry
matter percentages. A "grab" sample from each subsample was then
ground in a Wiley mill (1-mm mesh screen) prior to analysis at the
University of Florida Forage Evaluation Support Laboratory at
Gainesville, Florida. Also, collected from the 6-m portion of row
were fresh 2 to 3 kg subsamples of chopped PI 300086 elephantgrass
from two blocks for each harvest (six harvests yr^{-1}). These samples
were frozen and sent to the Bioprocess Engineering Research Laboratory
at Gainesville to determine methane potential. Due to limited
resources at the laboratory, however, one block sample was analyzed in
triplicate. Methane potential was estimated by bioassay procedures
outlined by Owen et al. (1979). Methane yields were calculated after
a 20-day fermentation period.

For Nitrogen analysis involved an aluminum block digestion of the
biomass material (Gallaher et al., 1975) followed by an automated
colorimetric determination of total N by a Technicon Auto Analyzer
(Technicon Instruments Corp., Tarrytown, NY). Crude protein content
(dry basis) was computed by multiplying the percent total N by 6.25.
The modified two-stage technique by Moore and Mott (1974) was used to
determine in vitro organic matter digestibility. Neutral detergent
fiber (ash-free) concentrations were determined using the procedure by
Van Soest and Wine (1967) with modifications suggested by Golding et
al. (1985).

For each of the response variables reported on in this Chapter,
with the exception of stand survival, the observations from the single

harvests within a multiple harvest treatment for each genotype were averaged or summed (depending on the parameter) into a single observation before statistical analyses were conducted. The means for most of the response variables from the single harvests are shown in tables contained in the Appendix.

Analysis of variance was performed by using the general linear model procedure of the Statistical Analysis System (SAS Institute Inc., 1982). When the F-test for treatment effects showed significance at the 5% level, this analysis was followed by Duncan's multiple range test (DMRT) to compare genotypes. Orthogonal polynomial procedures were used to determine the nature of the response over harvest frequencies. Statistical analyses were computed separately for the tall and short genotypes. The DMRT notations for tall genotypes are the usual a, b, and c letters, while the notations for the two short genotypes are letters x and y. Analysis of variance was not performed on values estimating methane potential because of limited observations.

Results and Discussion

Oven Dry Biomass Yields

Differences in dry biomass yield did not occur among the four "tall" elephantgrasses (PI 300086, Merkeron, N-43, and N-51) in either year (Tables 1 and 2). In 1986, yields for the tall-growing L79-1002 energycane were inferior to the tall elephantgrasses, but the following season differences did not occur. For all tall genotypes in both years, the biomass yields decreased as the frequency of harvest

Table 1. Oven dry biomass yield of elephantgrass genotypes grown under one, two, and three harvests per year at Green Acres research farm near Gainesville, FL, during 1986.

Genotype	Growth type	Oven dry biomass yield			
		Harvests in 1986			Average[§]
		1	2	3	
		Mg ha^{-1}			
PI 300086	tall	30.3	29.7	21.8	27.3a
Merkeron	tall	31.9	27.7	21.4	27.0a
N-43	tall	28.1	27.3	19.2	24.9a
N-51	tall	26.9	27.6	18.0	24.1a
L79-1002[†]	tall	19.6	18.7	14.3	17.5b
Overall average[¶]		27.4 L**Q**	26.2	18.9	
Selection No. 3[‡]	semi-dwarf	19.2	17.7	11.9	16.3x
Mott	dwarf	15.2	14.8	11.8	13.9y
Overall average[¶]		17.2 L**	16.2	11.8	

[†] Energycane (Saccharum spp.).

[‡] Pearlmillet x elephantgrass hybrid.

[§] Means in the same column followed by the same letter are not different at the 5% level according to DMRT.

[¶] Linear (L) and/or quadratic (Q) effects are significant over harvest treatments; P<0.01 (**) or P<0.05 (*).

Table 2. Oven dry biomass yield of elephantgrass genotypes grown
under one, two and three harvests per year at Green Acres
research farm near Gainesville, FL, during 1987.

Genotype	Growth type	Oven dry biomass yield			
		Harvests in 1987			Average[§]
		1	2	3	
		Mg ha^{-1}			
PI 300086	tall	23.6	20.3	12.9	18.9a
Merkeron	tall	26.3	20.8	16.2	21.1a
N-43	tall	24.3	20.6	14.9	19.9a
N-51	tall	21.2	18.1	16.1	18.5a
L79-1002[†]	tall	21.7	17.9	13.7	17.8a
Overall average[¶]		23.4 L**	19.5	14.8	
Selection No. 3[‡]	semi-dwarf	3.2	4.1	6.2	4.5y
Mott	dwarf	10.5	9.2	9.8	9.8x
Overall average		6.9	6.6	8.0	

[†]Energycane (Saccharum spp.).

[‡]Pearlmillet x elephantgrass hybrid.

[§]Means in the same column followed by the same letter are not
different at the 5% level according to DMRT.

[¶]Linear (L) and/or quadratic (Q) effects are significant over harvest
treatments; $P<0.01$ (**) or $P<0.05$ (*).

increased. The 2-year average yields for the four tall elephantgrasses with one, two, and three harvests yr^{-1} were 27, 24, and 18 Mg ha^{-1} yr^{-1}, respectively.

In 1986, the dry biomass yields for the "short" grasses (Selection No. 3 and 'Mott') decreased with more frequent harvests; however, trends were not found the following season. Selection No. 3 was superior in yield to Mott in 1986, but Mott yields were more than double those obtained from Selection No. 3 in 1987. That year, Selection No. 3 plants in all plots began to rapidly deteriorate, thus resulting in reduced biomass yield. Two-year average yields for Mott elephantgrass were 13, 12, and 11 Mg ha^{-1} yr^{-1} for one, two, and three harvests yr^{-1}.

Reduction of biomass yield with increased frequency of harvest is consistent with several reports in the literature (Watkins and Severen, 1951; Vicente-Chandler et al., 1959; Vélez-Santiago and Arroyo-Aguilú, 1981; Calhoun and Prine, 1985). In the present study, the yield advantage of full-season growth was probably due to the extended uninterrupted linear growth phase. At Gainesville, Calhoun (1985) reported the linear growth phase of dry matter accumulation for PI 300086 elephantgrass to be about 170 days with a crop growth rate of 23 g m^{-2} d^{-1}. When this growth phase is interrupted as with harvesting multiple times per season, the reduction in annual biomass yield can be attributed in part to the uncollected solar energy during the period between a harvest (canopy removal) and complete vegetative ground cover of the next ratoon growth phase. Consequently, the more

interruptions made during the season, the lower the annual biomass yield.

The biomass reduction from one to two harvests yr^{-1} obtained from the tall elephantgrass group in the present study (11%) was much smaller than those Mislevy et al. (1986) reported at Ona, Florida (67 and 69%). Contrastingly, in Puerto Rice--which has a full 12-month growing season--Samuels et al. (1983) reported higher annual dry biomass yields from elephantgrass harvested two times yr^{-1} as compared to harvesting one time. However, as the harvest frequency increased to three and six cuts per season, the yields declined. For one, two, three, and six harvests yr^{-1}, they reported annual dry biomass yields of 58, 74, 56, and 27 Mg ha^{-1}, respectively.

The biomass yields from the present study are somewhat lower than those from the reports cited earlier. However, given the droughty, infertile soils, the nonirrigated conditions, and the colder subtropical climate at the experimental site, the biomass yields from this study should be considered substantial.

Crude Protein, In Vitro Organic Matter Digestibility, and Neutral Detergent Fiber

Differences among tall grass genotypes in crude protein (CP) content did not occur in either year (Tables 3 and 4). The averages (over harvest frequency) for the tall grasses ranged from 5.7 to 6.2%, dry basis. The CP levels increased linearly with increasing frequency of harvest. The 2-year average CP contents for the four tall elephantgrasses were 4.0, 5.8, and 7.9% for one, two, and three harvests per season, respectively.

Table 3. Crude protein content of elephantgrass genotypes grown under one, two, and three harvests per year at Green Acres research farm near Gainesville, FL, during 1986.

Genotype	F-test[¶]	Crude protein			
		Harvests in 1986			Average[§]
		1	2	3	
		% , dry basis			
PI 300086		3.5	5.6	7.9	5.7a
Merkeron		3.9	5.3	8.1	5.8a
N-43		3.8	6.9	7.9	6.2a
N-51		3.7	5.3	8.2	5.7a
L79-1002[†]		3.9	5.5	7.8	5.7a
Overall average	L**	3.8	5.7	8.0	
Selection No. 3[‡]	L**	4.3x[§]	7.5x	9.7x	7.1
Mott	L**	4.7x	6.9x	8.8y	6.8
Overall average		4.5	7.2	9.2	

[†]Energycane (_Saccharum_ spp.).

[‡]Pearlmillet x elephantgrass hybrid.

[§]Means in the same column followed by the same letter are not different at the 5% level according to DMRT.

[¶]Linear (L) and/or quadratic (Q) effects are significant over harvest treatments; P<0.01 (**) or P<0.05 (*).

Table 4. Crude protein content of elephantgrass genotypes grown under one, two, and three harvests per year at Green Acres research farm near Gainesville, FL, during 1987.

Genotype	F-test[¶]	Crude protein			
		Harvests in 1987			Average[§]
		1	2	3	
		%, dry basis			
PI 300086		4.0	6.1	7.5	5.9a
Merkeron		4.5	5.9	7.5	6.0a
N-43		4.3	5.5	8.4	6.1a
N-51		4.5	5.6	7.7	6.0a
L79-1002[†]		4.5	5.7	7.3	5.8a
Overall average	L**	4.4	5.8	7.7	
Selection No. 3[‡]		–	–	–	
Mott	L**	5.8	7.3	10.4	7.8

[†] Energycane (Saccharum spp.).

[‡] Pearlmillet x elephantgrass hybrid.

[§] Means in the same column followed by the same letter are not different at the 5% level according to DMRT.

[¶] Linear (L) and/or quadratic (Q) effects are significant over harvest treatments; $P<0.01$ (**) or $P<0.05$ (*).

For the short grasses, CP levels also increased with more
frequent harvests. The 2-year average CP contents for Mott
elephantgrass were 5.3, 7.1, and 9.6% for one, two, and three harvests
yr^{-1}, respectively. Laboratory analyses were discontinued for
Selection No. 3 in 1987 due to herbage deterioration and subsequent
plant death.

In the overall analysis of in vitro organic matter
digestibilities (IVOMD), an interaction occurred between genotype and
harvest frequency in both years for the tall grass group (Tables 5 and
6). When L79-1002 energycane was deleted from the data set, the
interaction was not significant. Merkeron, N-43, and N-51
elephantgrasses did not differ in IVOMD in either season. The
genotype PI 300086 was significantly lower the first season but did
not differ from the other tall elephantgrasses the second season. The
IVOMDs for the elephantgrasses and energycane increased with the more
frequent harvests. The 2-year average IVOMDs for the four
elephantgrass genotypes were 40, 49, and 55% for the one, two, and
three harvests yr^{-1}, respectively.

In 1986, differences in IVOMD did not occur between Selection No. 3
and Mott genotypes. Also, IVOMD levels increased with more frequent
harvests. The 2-year average IVOMDs for Mott elephantgrass were 40,
54, and 57% for one, two, and three harvests yr^{-1}, respectively.

Similar ash-free neutral detergent fiber (NDF) values were
obtained from the tall elephantgrasses, though there was a tendency
for PI 300086 to be slightly higher than the others (Tables 7 and 8).
The NDF levels decreased with more frequent harvests; however, the

Table 5. *In vitro* organic matter digestibility (IVOMD) of
elephantgrass genotypes grown under one, two, and three
harvests per year at Green Acres research farm near
Gainesville, FL, during 1986.

Genotype	F-test[¶]	IVOMD			
		Harvests in 1986			Average[§]
		1	2	3	
		— % —			
PI 300086		37	47	55	46b
Merkeron		41	49	56	48a
N-43		39	52	56	49a
N-51		<u>40</u>	<u>49</u>	<u>56</u>	48a
Overall average	L** Q**	39	49	56	
L79-1002[†]	L** Q*	40	47	50	46
Selection No. 3[‡]	L** Q**	44x[§]	56x	56x	52
Mott	L** Q**	<u>43x</u>	<u>55x</u>	<u>58x</u>	52
Overall average		44	55	57	

[†]Energycane (*Saccharum* spp.).

[‡]Pearlmillet x elephantgrass hybrid.

[§]Means in the same column followed by the same letter are not
different at the 5% level according to DMRT.

[¶]Linear (L) and/or quadratic (Q) effects are significant over harvest
treatments; $P<0.01$ (**) or $P<0.05$ (*).

Table 6. In vitro organic matter digestibility (IVOMD) of elephantgrass genotypes grown under one, two, and three harvests per year at Green Acres research farm near Gainesville, FL, during 1987.

Genotype	F-test[¶]	IVOMD			
		Harvests in 1987			Average[§]
		1	2	3	
		%			
PI 300086		40	47	54	47a
Merkeron		42	50	55	49a
N-43		40	49	55	48a
N-51		42	47	55	48a
Overall average	L**	41	48	55	
L79-1002[†]	L**	46	47	50	48
Selection No. 3[‡]		–	–	–	
Mott	L** Q**	36	53	56	48

[†]Energycane (Saccharum spp.).

[‡]Pearlmillet x elephantgrass hybrid.

[§]Means in the same column followed by the same letter are not different at the 5% level according to DMRT.

[¶]Linear (L) and/or quadratic (Q) effects are significant over harvest treatments; $P < 0.01$ (**) or $P < 0.05$ (*).

Table 7. Ash-free neutral detergent fiber (NDF) content of
         elephantgrass genotypes grown under one, two, and three
         harvests per year at Green Acres research farm near
         Gainesville, FL, during 1986.

Genotype	F-test[¶]	NDF			
		Harvests in 1986			Average[§]
		1	2	3	
		%, dry basis			
PI 300086		83	78	76	79a
Merkeron		81	76	73	77bc
N-43		81	75	74	77c
N-51		<u>82</u>	<u>77</u>	<u>74</u>	77b
Overall average	L** Q**	82	77	74	
L79-1002[†]		77	78	77	77
Selection No. 3[‡]		76	72	68	72y
Mott		<u>76</u>	<u>73</u>	<u>70</u>	73x
Overall average	L**	76	73	69	

[†]Energycane (<u>Saccharum</u> spp.).

[‡]Pearlmillet x elephantgrass hybrid.

[§]Means in the same column followed by the same letter are not
different at the 5% level according to DMRT.

[¶]Linear (L) and/or quadratic (Q) effects are significant over harvest
treatments; $P<0.01$ (**) or $P<0.05$ (*).

Table 8. Ash-free neutral detergent fiber (NDF) content of
elephantgrass genotypes grown under one, two, and three
harvests per year at Green Acres research farm near
Gainesville, FL, during 1987.

Genotype	F-test[¶]	NDF			
		Harvests in 1987			
		1	2	3	Average
		——————— %, dry basis ———————			
PI 300086	L**	79a[§]	78a	76b	78
Merkeron	L** Q*	79a	75b	75c	76
N-43	L**	80a	76b	74c	77
N-51	L**	80a	77a	74c	77
L79-1002[†]	L**	72b	76ab	78a	75
Overall average		78	76	75	
Selection No. 3[‡]		–	–	–	
Mott	L**	78	72	70	73

[†]Energycane (Saccharum spp.).

[‡]Pearlmillet x elephantgrass hybrid.

[§]Means in the same column followed by the same letter are not
different at the 5% level according to DMRT.

[¶]Linear (L) and/or quadratic (Q) effects are significant over harvest
treatments; $P<0.01$ (**) or $P<0.05$ (*).

magnitude of the decline was small. The 2-year average NDF

concentrations for the four tall elephantgrasses were 81, 76, and 74%

(dry basis) for one, two, and three harvests yr^{-1}, respectively. For

the energycane (L79-1002), NDF levels were unchanged over harvest

treatments in 1986 while the levels surprisingly increased linearly

with more frequent harvests the following season.

Selection No. 3 and Mott genotypes differed slightly in NDF

during 1986. The NDF levels decreased with increasing cutting

frequency. The 2-year average NDF concentrations for Mott were 77,

73, and 70% for one, two, and three harvests yr^{-1}, respectively.

In general, the quality of elephantgrass forage in terms of CP,

IVOMD, and NDF, becomes more favorable as the number of harvests per

season increases. With more frequent harvesting of both tall and

short elephantgrasses, CP and IVOMD levels increase while NDF

concentrations decline. Among the four tall elephantgrasses,

PI 300086 had a tendency to be slightly lower in IVOMD and higher in

NDF than the others.

Although direct statistical comparisons between tall and short

elephantgrasses cannot be made in this study due to different, but

similar, plot locations, some interesting trends are worth noting.

Crude protein averages recorded for Mott were generally one to two

percentage points higher than the average values recorded for the tall

types. Averages for IVOMD were one to two percentage points higher

under three harvests per season. With two harvests per season, Mott

IVOMD averages were approximately five percentage points higher,

probably the result of a major increase in the stem portion of the

total above-ground parts of tall elephantgrass plants. Also, Mott NDF levels tended to be from three to five percentage points lower.

The more favorable quality measurements obtained from Mott can be attributed to the greater fraction of leaves in the total above-ground portions of dwarf plants and higher stem quality. In Florida, Boddorff and Ocumpaugh (1986) obtained stem IVOMD values for dwarf elephantgrass genotypes ranging from 72% in October to 60% in January while tall hybrid Pennisetum genotypes ranged from 66 to 45% over the same period. Stem crude protein contents for the dwarf types ranged from 11% in October to 6% in January (dry basis) compared with 7 to 4% for the tall hybrids. The leaf blade made up 80% of the total sample in October for the dwarf genotypes. This was nearly double the value recorded for the tall hybrids.

Winter Survival

The percent stand survival was recorded after spring growth initiation in 1988 (Table 9). The elephantgrass PI 300086 survived the conditions during 1986-87; however, major stand losses occurred over the 1987-88 winter following the second growing season in plots harvested multiple times per year. Calhoun and Prine (1985) also reported major losses in PI 300086 stands with multiple harvest frequencies at a site near Gainesville.

Merkeron, N-43, N-51, and Mott elephantgrasses and L79-1002 energycane tolerated the harvest frequencies included in the present study and survived the two winters at Gainesville. Selection No. 3 plots were almost completely void of live plants in the spring of

Table 9. Stand survival of elephantgrass genotypes following the 1986-87 growing seasons with plots harvested one, two, and three times per year at Green Acres research farm near Gainesville, FL.

Genotype	F-test[#]	Stand survival[†]		
		Harvests per year		
		1	2	3
		%———		
PI 300086	L** Q**	59b[¶]	8b	8b
Merkeron		84a	75a	81a
N-43	Q**	81a	72a	81a
N-51		80a	69a	81a
L79-1002[‡]		67b	69a	81a
Selection No. 3[§]		0y	1y	0y
Mott		79x	77x	71x

[†]Percentage of stubble area initiating spring growth on 6 Apr. 1988.

[‡]Energycane (Saccharum spp.).

[§]Pearlmillet x elephantgrass hybrid.

[¶]Means in the same column followed by the same letter are not different at the 5% level according to DMRT.

[#]Linear (L) and/or quadratic (Q) effects are significant over harvest treatments; P<0.01 (**) or P<0.05 (*).

1988. Selection No. 3 plants in all plots began to deteriorate rapidly during the 1987 season. That year a heavy infestation of the two-lined spittlebug (<u>Prosapia</u> <u>bicincta</u> Say) occurred on Mott and Selection No. 3. The primary cause of accelerated plant death of Selection No. 3 was attributed to the spittlebugs.

Methane Production

Results of the bioassays performed on fresh PI 300086 elephantgrass suggest that methane yield kg^{-1} volatile solid (VS) after a 20-day fermentation period increases with more frequent harvesting (Table 10). This trend is consistent with the findings of Calhoun and Prine (1985) and Shiralipour and Smith (1985). However, the levels of methane yield kg^{-1} VS were overall somewhat lower than those obtained by the reports cited above. Estimated methane production ha^{-1} was substantially lower overall compared to values reported by the former study. This was the result of lower dry biomass production and methane yield kg^{-1} VS.

The data suggest that harvesting two times per season results in slightly higher methane production ha^{-1}; however, large differences between harvest frequencies were not apparent. It is possible that the production of biodegradable plant materials per unit land area (i.e., biodegradable within a reasonable period of time) is similar for the three harvest frequency regimes. If so, the biodegradable materials would be more diluted in full-season growth and concentrated in plants harvested three times per season. It is also possible that the quantity-quality compromising

Table 10. Average predicted methane production of PI 300086
elephantgrass harvested one, two, and three times per
season at Green Acres research farm near Gainesville, FL,
during the 1986-87 growing seasons.

Harvests per season	Annual dry biomass yield	Volatile solids	Average methane yield[†]	Annual methane production
	Mg ha^{-1}	%	std m^3 kg^{-1} VS	std m^{3}x10^3 ha^{-1}
1	27.0	96.4	0.185[‡]	4.8
2	25.0	95.7	0.217	5.2
3	17.3	94.5	0.277	4.5

[†]Determined from one sample per harvest over two seasons.

[‡]Methane yield measured at 15.5°C and one atmosphere.

harvest frequency between these two extremes--i.e., harvesting two times per season--will result in slightly higher methane production.

In contrast, Calhoun and Prine (1985) showed a clear-cut advantage with full-season growth in annual methane production ha^{-1} over multiple harvests. In their study, the high values for predicted methane production ha^{-1} were mainly due to the large biomass yields of single annual harvests and the major declines in yield of multiple cuts. Although full-season growth produced the highest biomass yields in the present study, major declines in production under two and three harvests per season did not occur.

Animal Performance

Much research has been conducted with elephantgrass throughout the tropics and subtropics since the early 1900s. The objectives of most studies of the past have centered on ruminant nutrition because of the widespread utilization of this forage as a green chop and silage feed.

Although direct animal performance data were not collected, it is reasonable to assume that the forages harvested in the present study can be used in cattle operations, either totally or in combination with energy systems, depending on the current market circumstances. When fed ad libitum as a soilage crop, elephantgrass forages from the tall genotypes and three harvests per season (2-year average CP and IVOMD values were 7.9% and 55%, respectively) should result in a positive energy balance for most classes of cattle (National Research Council, 1984). Forages grown under two harvests per season (2-year

average CP and IVOMD values were 5.8% and 49%, respectively) should

result in a nutritional level that is near maintenance for some

classes, mature non-lactating cows for example, provided voluntary

intakes are adequate. [The author is assuming that IVOMD is a

reasonable estimate of total digestible nutrient (TDN) content.] In

Venezuela, Arias (1979) measured daily animal intakes with

elephantgrass forage over a 200-day period beginning with 8-month-old

calves. Daily intakes ranged from 2.1 to 3.1 kg DM/100 kg liveweight

with forages gathered at the flowering stage to early vegetative

increase. Daily liveweight gains ranged from -0.1 to 0.8 kg per head.

In Brazil, Gonçalez et al. (1979) working with two elephantgrass

cultivars reported daily intakes of 1.9 and 2.3 kg DM/100 kg

liveweight in cattle. The forage _in vitro_ dry matter digestibilities

for the corresponding intake values were 46 and 47%, respectively.

Daily animal performance under _ad libitum_ conditions should be

somewhat higher for Mott dwarf elephantgrass compared to the tall

types. This prediction is based on the improved quality attributes

that were observed in the present study which included higher recorded

values for crude protein and IVOMD and lower values for NDF. Burton

et al. (1969) reported a 20% greater average daily gain for steers

grazing dwarf pearlmillet as compared to those grazing tall types.

Dwarf elephantgrasses may turn out to be inferior to tall types on an

animal product ha^{-1} basis and under soilage feeding conditions because

the better quality may not make up for its much lower biomass yield.

Conclusions

Elephantgrass produces substantial biomass yields on dry, infertile sites and under the colder subtropical conditions of North Central Florida. As the number of harvests per season increases, biomass yields decline (the yield response of Mott dwarf elephantgrass may be an exception with the harvest frequencies included in the present study) while forage crude protein and IVOMD levels and methane yields kg^{-1} VS increase. Neutral detergent fiber levels gradually decrease; however, major reductions do not occur.

Variation in survival tolerance to increased harvest frequency and colder subtropical winters exists among genotypes. The elephantgrass genotypes Merkeron, N-43, N-51, and Mott, and the L79-1002 energycane survived the experimental conditions and could be recommended for planting in North Central Florida. The genotype PI 300086 elephantgrass was susceptible to winterkill, particularly when harvested multiple times per season. An almost complete loss of stand occurred in the semi-dwarf Selection No. 3 (Pennisetum hybrid) plots during the study. Therefore, PI 300086 and Selection No. 3 are not suitable for the area.

Two harvests per season appeared to be the best compromise between biomass quantity and quality (methane yield kg^{-1} VS), thus resulting in the highest estimate for methane production ha^{-1}. Since the other harvest treatments resulted in similar predicted production levels, the final analysis as to the best harvest regime to use in a methane production system must come from an evaluation of production costs and net energy gains.

Finally, the forages resulting from two and three harvests per season could be utilized, either solely or in combination with energy production systems, in several types of cattle operations. These forages should provide an almost complete supply of nutrients required for certain beef cattle classes such as mature cows and replacement heifers. For high-producing animals such as lactating dairy cows and feedlot beef animals, these forages can provide some of the required nutrients and the needed roughage for maintaining healthy ruminal functions, when included as a portion of animal diets.

CHAPTER 3
SILAGE CHARACTERISTICS OF ELEPHANTGRASS AND ENERGYCANE
AS AFFECTED BY HARVEST FREQUENCY AND GENOTYPE

Introduction

Elephantgrass was ensiled and fed to cattle in Florida as early as 1933 by Neal et al. (1935). Using the ensiling process to preserve thick-stemmed, erect grasses such as elephantgrass is generally the preferred method over other forms of storage. Making hay with elephantgrass is not easily accomplished because of the problems associated with the solar drying of thick stems and the large mass of plant material produced per unit land area. The accumulation of forage in the field (stockpiling) is generally an ineffective method of storage because of the rapid decline in forage quality with advancing plant age (Gomide et al., 1969).

Reports in the literature on the ensiling of elephantgrass are not all positive. Davies ensiled chopped elephantgrass in miniature cement tower silos which held approximately 135 kg of fresh material. The elephantgrass was 2.5 m tall when harvested and contained 24% dry matter (DM). Silos were sampled 50 days after packing. He reported that a 45% loss in DM had occurred during storage which led him to state that "there appears to be some peculiarity with this grass [elephantgrass] in that it does not make good silage without the addition of molasses" (1963, pp. 318-319). Conversely, Brown and Chavalimu (1985) successfully ensiled 5-week-old elephantgrass

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regrowth by hand-packing chopped plant material into two nested
polyethylene bags. Silage sampling took place after 2.5 months of
storage. A 96% DM recovery was reported.

The objectives of the following silage study, which is a
continuation of the experiment previously described in Chapter 2, were
to determine if elephantgrass and energycane gathered under different
harvest frequency regimes could be adequately preserved as silage and
to identify potential problems that could exist in the conversion of
the silage into animal or energy products.

Materials and Methods

Much of the fresh chopped plant materials generated during 1986-87
from the harvest frequency x genotype experiment described in Chaper 2
was ensiled using 20-liter plastic paint pails as portable silos.
Genotypes ensiled included PI 300086, Merkeron, and Mott elephantgrasses
and L79-1002 energycane. The field plots were harvested one, two, and
three times per season. During each harvest, biomass from three blocks
was ensiled for each treatment combination. Tall genotypes were
mechanically harvested with a John Deere model 3940 forage harvester,
which chopped the majority of the plant materials into 2- to 3-cm length
pieces. Mott dwarf elephantgrass could not be effectively harvested
with the forage harvester. It was cut down with a Stihl model FS 96
brushcutter and then chopped using the forage harvester. Each silo
was lined with two, 4-mil thick Ironclad trash compactor plastic
bags (North American Plastics Corp., Aurora, IL), then hand-packed
with 8 to 11 kg of fresh chopped biomass. After filling, the

liner bags were separately tied off with jute string. Each silo was then weighed.

During field harvesting, subsamples were collected, then air-dried at 60°C to compute DM percentage. These samples were then used to determine the forage quality parameters reported earlier in Chapter 2. In addition, fresh subsamples were collected in reclosable freezer bags (2.7-mil thick) and frozen. These samples were used to determine water soluble carbohydrate content and buffering capacity of original biomass prior to ensiling.

Ensiling dates corresponded to the harvest periods reported in Chapter 2. The silos filled during the 1986 season were sampled 10 months after the ensiling dates. The silos filled during the 1987 season were all sampled during the second week of February 1988. The silos were weighed again just prior to sampling in order to calculate DM recovery. The weight of a paint pail plus two trash compactor bags was substrated from the weight of each packed silo before DM recovery was computed.

During silo sampling, the spoilage that commonly occurred in the top 4 to 5 cm of the stored biomass was discarded. The remaining silage was placed in a 114-liter container and thoroughly mixed. A sample was taken, placed in a freezer bag, and frozen immediately. Another sample was collected and oven-dried at 60°C to compute DM percentage. It was then ground in a Wiley mill (1-mm mesh screen) prior to analysis at the University of Florida Forage Evaluation Support Laboratory at Gainesville, Florida, where the modified two-stage technique by Moore and Mott (1974) was used to determine _in_

<u>vitro</u> organic matter digestibility. This procedure was performed on the original biomass and corresponding silage at the same time, using the same batch of rumen fluid inoculum.

At a later date, 25 g from each frozen silage sample were placed in a blender with 225 ml of deionized water. The sample was then lacerated for 2 minutes and filtered through several layers of cheesecloth. It was thoroughly pressed to remove as much extract as possible. This extract was used for silage quality determinations including pH, acetic, butyric, and lactic acid contents (dry basis), and ammoniacal N as a percentage of total N.

A Fisher Accumet digital pH meter (Fisher Scientific Corp., Pittsburgh, PA) calibrated with pH 4 and 7 buffer solutions, was used to measure silage pH.

Acetic, butyric, and lactic acid levels were determined using a Perkin-Elmer Sigma 3B gas chromatograph (Perkin-Elmer, Norwalk, CT). Chromatograph specifications are as follows: <u>Column packing</u>, GP 10% SP-1000/1% H_3PO_4 on 100/120 Chromosorb W AW (Supelco, Inc., Bellefonte, PA); <u>Column type</u>, 1.8 m x 2 mm ID glass; <u>Column temperature</u>, 115-135°C, varied with conditions; <u>Flow rate</u>, 30 ml/min., N_2; <u>Detector</u>, FID; <u>Sample injection size</u>, 1.0 μl. The gas chromatograph was calibrated with standards made from Supelco volatile and non-volatile acid standard mixes. Procedures used to prepare methyl derivatives of lactic acid from silage extracts were those outlined by Supelco, Inc. (1985).

Analysis of total N in silage involved an aluminum block digestion of fresh 5-g samples (Gallaher et al., 1975), followed by a

colorimetric determination using a Technicon Auto Analyzer (Technicon Instruments Corp., Tarrytown, NY). For ammoniacal N determinations, silage extracts were analyzed by using an adaptation of the ammonia-salicylate reaction, followed by Technicon colorimetric procedures (Noel and Hambleton, 1976).

The phenolsulfuric acid colorimetric procedure by Dubois et al. (1956) and a Spectronic 20 colorimeter-spectrophotometer (Bausch and Lomb Inc., Rochester, NY) were used to measure water soluble carbohydrate content (dry basis) of original biomass before ensiling.

Buffering capacity, expressed as the number of milliequivalents of NaOH required to raise one kg of biomass DM from pH 4 to 6, was measured on fresh plant samples before ensiling by methods used by Playne and McDonald (1966).

For each of the response parameters reported on in this chapter, the observations recorded for the single harvests within a multiple harvest treatment for each genotype were averaged into a single observation before statistical analyses were conducted. The means for most of the response variables from single harvests are shown in tables contained in the Appendix.

Statistical procedures used to analyze silage data were the same as those described in Chapter 2.

Results and Discussion

Biomass Characteristics Before Ensiling

Dry matter (DM) contents for 1986-87 are presented in Tables 11 and 12. Declining DM contents with more frequent harvesting was the

Table 11. Dry matter content of elephantgrass and energycane grown
under one, two, and three harvests in 1986 at Green Acres
research farm near Gainesville, FL.

Genotype	F-test[¶]	Dry matter		
		Harvests in 1986		
		1	2	3
		%		
PI 300086	L**	33a[§]	26a	19b
Merkeron	L**	33a	25a	20ab
L79-1002[†]	L**	31a	24a	21a
Mott	L**	29	23	21

[†]Energycane (Saccharum spp.).

[§]Means in the same column followed by the same letter are not
different at the 5% level according to DMRT.

[¶]Linear (L) and/or quadratic (Q) effects are significant over harvest
treatments, $P<0.01$ (**) or $P<0.05$ (*).

Table 12. Dry matter content of elephantgrass and energycane grown under one, two, and three harvests in 1987 at Green Acres research farm near Gainesville, FL.

Genotype	F-test[¶]	Dry matter Harvests in 1987		
		1	2	3
		— % —		
PI 300086	L** Q**	37a[§]	26a	20b
Merkeron	L**	34b	25a	20b
L79-1002[†]	L** Q*	33b	25a	22a
Mott	L** Q**	33	24	25

[†]Energycane (<u>Saccharum</u> spp.).

[§]Means in the same column followed by the same letter are not different at the 5% level according to DMRT.

[¶]Linear (L) and/or quadratic (Q) effects are significant over harvest treatments, P<0.01 (**) or P<0.05 (*).

general pattern which is in agreement with the results reported by Vicente-Chandler et al. (1959). Gomide et al. (1969) showed a strong linear increase in DM content with advancing age of elephantgrass plants. The harvest frequencies used in the present study provided plant materials averaging from 19 to 37% DM for ensiling.

The optimum forage DM content for ensiling is generally considered to be between 28 to 35%. Ensiling forages with DM contents below 26% are subject to undesirable clostridial fermentation (Harris, 1984). Low DM silages require higher organic acid concentrations and lower pHs to inhibit the growth and proliferation of Clostridia bacteria. Clostridial growth is suppressed when the silage DM content is above 35%. However, excluding oxygen during the packing of high DM plant materials is more difficult because such materials are of lower density (Vetter and Von Glan, 1978).

Full-season growth of elephantgrass genotypes contained the lower levels of water soluble carbohydrates (WSCHO) whereas the more immature forages from multiple harvest treatments had the higher levels (Table 13). It should be noted that variations in WSCHO content existed between individual cuttings within the multiple harvest regimes. In 1987, the mean WSCHO contents of the tall elephantgrasses (PI 300086 and Merkeron) for the first, second, and third cuttings of the three harvests per season treatment were 10.4, 10.6, and 3.0% (dry basis), respectively. With the two harvests treatment, the levels were 9.9 and 6.0% for the first and second cuttings, respectively. Similar trends were observed for L79-1002 energycane. Low temperatures just prior to the final harvesting

Table 13. Water soluble carbohydrate (WSCHO) content of elephantgrass
and energycane grown under one, two, and three harvests in
1987 at Green Acres research farm near Gainesville, FL.

Genotype	F-test[¶]	WSCHO		
		Harvests in 1987		
		1	2	3
		%, dry basis		
PI 300086	L** Q*	5.8b[§]	8.4ab	8.2a
Merkeron	L**	4.4b	7.6b	7.9a
L79-1002[†]	L** Q**	9.5a	9.6a	7.1b
Mott	L**	2.6	4.6	7.0

[†]Energycane (Saccharum spp.).

[§]Means in the same column followed by the same letter are not
different at the 5% level according to DMRT.

[¶]Linear (L) and/or quadratic (Q) effects are significant over harvest
treatments, P<0.01 (**) or P<0.05 (*).

period in 1987 caused considerable frost damage, particularly to the youngest ratoon plants. The low levels of WSCHO were attributed to cold damage. An interesting inconsistency occurred when the youngest ratoon plants of PI 300086 and Merkeron elephantgrass (mean WSCHO content of plants before ensiling was 3.0%, dry basis) from the third cutting were ensiled. The mean pH value of silages made from these cold-damaged plants was 3.9--lower than expected--while the mean lactic acid concentration was 6.8% (dry basis), which was higher than expected, considering the low WSCHO levels in fresh biomass before ensiling. Further research is needed before explanations can be given.

The WSCHO content of full-season L79-1002 energycane growth was substantially higher than those of the elephantgrasses. Although linear and quadratic effects are significant, it is still unclear how WSCHO levels in energycane are affected by harvest frequency.

In Brazil, Veiga and Campos (1975) reported an average WSCHO content of 6.5% (dry basis) for elephantgrass harvested at an advanced stage of growth. With elephantgrass cut at 55 days of age, Tosi et al. (1983) reported a mean content of 17.0%.

The buffering capacities of PI 300086 and L79-1002 forages increased with more frequent harvesting (Table 14). Values measured for full-season growth were exceptionally low. For both genotypes, all values were substantially lower than those of other forage crops reported by Woolford (1984). Woolford reviewed earlier literature and presented a range of buffering capacities. The highest buffering capacities shown were from temperate legumes including alfalfa (Medicago sativa L.) and red clover (Trifolium pratense L.) with

Table 14. Buffering capacity of PI 300086 elephantgrass and L79-1002 energycane grown under one, two, and three harvests in 1987 at Green Acres research farm near Gainesville, FL.

Genotype	F-test[¶]	Buffering capacity		
		Harvests in 1987		
		1	2	3
		Meq NaOH kg^{-1} DM[†]		
PI 300086	L**	52a[§]	78a	112b
L79-1002	L** Q**	45a	131a	146a

[†]Milliequivalents of NaOH required to raise the pH of one kg of biomass DM from 4.0 to 6.0.

[§]Means in the same column followed by the same letter are not different at the 5% level according to DMRT.

[¶]Linear (L) and/or quadratic (Q) effects are significant over harvest treatments, $P<0.01$ (**) or $P<0.05$ (*).

values of 480 and 560 meq NaOH kg^{-1} DM, respectively. Temperate

grasses including orchardgrass (Dactylis glomerata L.), perennial

ryegrass (Lolium perenne L.), and Italian ryegrass (L. multiflorum

Lam.) had intermediate values of 300, 350, and 430 meq, respectively.

Forage corn (Zea mays L.) had the lowest buffering capacity of 200

meq. Woolford suggested that the low buffering capacity partly

explains why corn is easier to ensile than other crops. It is

interesting to note the similarities between elephantgrass,

energycane, and forage corn. These tropical C-4 grass plants have

upright growth habits and large coarse stems where soluble

carbohydrates are stored. The possibility exists that other tropical

grasses with the same morphological features may tend to possess low

buffering capacities.

Tropical forages with low buffering capacities would require

smaller concentrations of lactic acid and other organic acids to be

produced during ensiling in order to reach an ideal low pH where

microbial activity would cease and preservation would occur. Thus,

there would be less of a requirement in standing forages for high

levels of available substrates (WSCHO) needed for a successful

ensilage fermentation.

According to Playne and McDonald (1966) the anionic moiety,

mainly organic acids, of plant biomass contributes 68 to 80% to the

buffering capacity while plant proteins make up 10 to 20%.

Silage Characteristics

Average pH values recorded during both seasons for the tall
elephantgrass silages (PI 300086 and Merkeron) ranged narrowly from 3.8
to 4.0 (Tables 15 and 16). In 1986, pH values for Merkeron increased
linearly with an increase in harvest frequency. Also, during both
seasons pH values for L79-1002 energycane and Mott dwarf elephantgrass
silages increased linearly with more frequent harvesting. The highest
pH values were consistently obtained from silages made from immature
Mott forages gathered from plots harvested three times per season.

During 1986, mean lactic acid contents of PI 300086 and Merkeron
silages (Table 17) ranged from 3.0 to 3.6% (dry basis). The following
season lactic acid levels for these tall elephantgrasses increased as
harvest frequency increased with means ranging from 1.4 to 5.3% (Table
18). Lactic acid contents for L79-1002 energycane silages decreased
linearly with more frequent harvesting during 1986, whereas no effect
was observed the next year. The lowest values were obtained from
L79-1002 silages made from the most immature plants during 1986. Mean
lactic acid contents were fairly constant for Mott silages.

Overall, acetic acid contents generally increased as the harvest
frequency increased (Tables 19 and 20). Mean acetic acid contents for
PI 300086 and Merkeron silages ranged from 0.25 to 1.58% (dry basis).
The higher means were usually obtained from L79-1002 energycane and Mott
elephantgrass silages that were made with immature plant materials from
multiple harvest treatments.

Silages made with plant materials from full-season growth in 1987
had as low or lower pH values than those made from immature plants

Table 15. The pH of elephantgrass and energycane silages made from plants grown under one, two, and three harvests during 1986 at Green Acres research farm near Gainesville, FL.

Genotype	F-test[¶]	Silage pH		
		Harvests in 1986		
		1	2	3
PI 300086		3.8a[§]	3.9a	4.0b
Merkeron	L**	3.8a	3.9a	4.0b
L79-1002[†]	L**	3.8a	3.9a	4.3a
Mott	L**	4.0	4.1	4.3

[†]Energycane (Saccharum spp.).

[§]Means in the same column followed by the same letter are not different at the 5% level according to DMRT.

[¶]Linear (L) and/or quadratic (Q) effects are significant over harvest treatments, P<0.01 (**) or P<0.05 (*).

Table 16. The pH of elephantgrass and energycane silages made from
           plants grown under one, two, and three harvests in 1987 at
           Green Acres research farm near Gainesville, FL.

Genotype	F-test[¶]	Silage pH Harvests in 1987		
		1	2	3
PI 300086		3.8a[§]	3.8b	3.8a
Merkeron		3.8b	3.8b	3.9a
L79-1002[†]	L*	3.8a	4.0a	4.0a
Mott	L**	4.0	4.2	4.4

[†]Energycane (Saccharum spp.).

[§]Means in the same column followed by the same letter are not
different at the 5% level according to DMRT.

[¶]Linear (L) and/or quadratic (Q) effects are significant over harvest
treatments, $P < 0.01$ (**) or $P < 0.05$ (*).

Table 17. Lactic acid content of elephantgrass and energycane silages
made from plants harvested one, two, and three times in
1986 at Green Acres research farm near Gainesville, FL.

Genotype	F-test[¶]	Lactic acid		
		Harvests in 1986		
		1	2	3
		%, dry basis		
PI 300086		3.3a[§]	3.0a	3.6a
Merkeron		3.3a	3.4a	3.6a
L79-1002[†]	L**	3.2a	2.8a	0.7b
Mott		3.7	3.3	2.4

[†]Energycane (<u>Saccharum</u> spp.).

[§]Means in the same column followed by the same letter are not
different at the 5% level according to DMRT.

[¶]Linear (L) and/or quadratic (Q) effects are significant over harvest
treatments, $P<0.01$ (**) or $P<0.05$ (*).

Table 18. Lactic acid content of elephantgrass and energycane silages made from plants harvested one, two, and three times in 1987 at Green Acres research farm near Gainesville, FL.

Genotype	F-test[¶]	Lactic acid		
		Harvests in 1987		
		1	2	3
		%, dry basis		
PI 300086	L** Q*	1.4a[§]	2.6b	5.3a
Merkeron	L*	2.2a	4.1a	4.5ab
L79-1002[†]		1.7a	2.2b	3.0b
Mott		2.3	3.2	2.0

[†] Energycane (<u>Saccharum</u> spp.).

[§] Means in the same column followed by the same letter are not different at the 5% level according to DMRT.

[¶] Linear (L) and/or quadratic (Q) effects are significant over harvest treatments, P<0.01 (**) or P<0.05 (*).

Table 19. Acetic acid content of elephantgrass and energycane silages made from plants harvested one, two, and three times in 1986 at Green Acres research farm near Gainesville, FL.

Genotype	F-test[¶]	Acetic acid		
		Harvests in 1986		
		1	2	3
		— %, dry basis —		
PI 300086		0.40a[§]	0.33a	1.49b
Merkeron	L*	0.40a	0.75a	1.58b
L79-1002[†]	L** Q*	0.43a	0.65a	2.55a
Mott		0.72	1.45	2.19

[†]Energycane (Saccharum spp.).

[§]Means in the same column followed by the same letter are not different at the 5% level according to DMRT.

[¶]Linear (L) and/or quadratic (Q) effects are significant over harvest treatments, P<0.01 (**) or P<0.05 (*).

Table 20. Acetic acid content of elephantgrass and energycane silages
made from plants harvested one, two, and three times in
1987 at Green Acres research farm near Gainesville, FL.

Genotype	F-test[¶]	Acetic acid Harvests in 1987		
		1	2	3
		%, dry basis		
PI 300086		0.25b[§]	0.73a	0.69b
Merkeron	L**	0.29b	0.77a	1.32ab
L79-1002[†]	L*	0.46a	1.65a	1.71a
Mott	L** Q**	0.28	2.18	2.21

[†]Energycane (Saccharum spp.).

[§]Means in the same column followed by the same letter are not
different at the 5% level according to DMRT.

[¶]Linear (L) and/or quadratic (Q) effects are significant over harvest
treatments, $P<0.01$ (**) or $P<0.05$ (*).

which were gathered from plots harvested multiple times per season.
(This also occurred in 1986.) At first, these data appear to be
inconsistent since the original fresh biomass from mature full-season
plants that year contained the lowest WSCHO concentrations, with
L79-1002 energycane being an exception (Table 13). In addition,
corresponding silages contained lower concentrations of lactic and
acetic acids, compared to those silages made from immature plants.
These results can be explained by using the buffering capacities of
fresh materials that were recorded prior to ensiling in 1987 (Table
14). The fresh forages from full-season plants contained
exceptionally low buffering capacities (i.e., low resistance to
changes in pH). Therefore, lower concentrations of fermentative acids
(lactic and acetic) were needed to reduce the biomass pH to low levels
where bacterial activity stops. Since smaller amounts of these
organic acids were required, lower concentrations of convertible
substrates (WSCHO) in the original forages of full-season growth were
needed to reach that end-point.

Butyric acid concentration and ammoniacal N content, expressed as
a percentage of total biomass N, in silage indicate the extent of
undesirable secondary fermentations by Clostridia bacteria.
Saccharolytic and proteolytic clostridial fermentations can result in
greater losses of dry matter as compared to a lactic acid
fermentation. In addition, end-products formed by clostridial
fermentations can negatively affect voluntary intake in ruminant
animals (Wilkinson et al., 1976).

Mean butyric acid levels (not shown) in PI 300086, Merkeron, and L79-1002 silages were low during both seasons. Average butyric acid concentrations in these silages ranged from values near zero to 0.02% (dry basis). For Mott silages, means ranged from values near zero to 0.12%. No treatment effects were obtained.

Ammoniacal N percentages of total N for PI 300086 elephantgrass and L79-1002 energycane silages for 1987 are listed in Table 21. Mean ammoniacal N values for both grasses ranged from 7.7 to 11.0%. For PI 300086 elephantgrass silages, a linear decrease (P<0.01) in ammoniacal N percentages with more frequent harvesting was obtained.

Several researchers from Brazil have conducted silage studies with elephantgrass. Silveira et al. (1979) ensiled direct-cut 62-day regrowth from four genotypes of elephantgrass. After 150 days of storage, samples were collected. Mean silage pH values and lactic acid contents varied from 4.1 to 4.4 and from 5.8 to 7.9% (dry basis), respectively. Average acetic acid levels ranged from 2.7 to 5.9% (dry basis). Butyric acid levels reported varied from 0.01 to 0.03% (dry basis) whereas mean ammoniacal N percentages of total N ranged from 13.3 to 17.6. With elephantgrass ensiled at 9 to 10 weeks of age, Vilela et al. (1983) reported an average silage pH of 3.9. Mean lactic, acetic, and butyric acid contents were 1.5, 2.0, and 0.23% (dry basis), respectively. The mean ammoniacal N level was 17.3% of total N. Veiga and Campos (1975) ensiled direct-cut elephantgrass at an advanced stage of growth. The forages used contained 28% DM and 3.6% crude protein (dry basis). With their controls (no additives) the mean silage pH and lactic acid content was 3.9 and 2.2% (dry basis), respectively.

Table 21. Ammoniacal N percentage of total N in PI 300086
elephantgrass and L79-1002 energycane silages made from
plants grown under one, two, and three harvests in 1987 at
Green Acres research farm near Gainesville, FL.

Genotype	F-test[¶]	Ammoniacal N		
		Harvests in 1987		
		1	2	3
		%		
PI 300086	L**	11.0a[§]	10.5a	9.6a
L79-1002	L* Q*	10.1a	7.7b	8.6a

[§]Means in the same column followed by the same letter are not
different at the 5% level according to DMRT.

[¶]Linear (L) and/or quadratic (Q) effects are significant over harvest
treatments, P<0.01 (**) or P<0.05 (*).

Many attempts have been made to index silage fermentation quality according to various guidelines. The Breirem and Ulvesli system outlined by McCullough (1978) characterizes desirable silages as those having pH values lower than 4.2; lactic and acetic acid contents ranging from 1.5 to 2.5% and from 0.5 to 0.8% (dry basis), respectively; butyric acid levels that are below 0.1% (dry basis) and ammoniacal N levels that do not exceed 5 to 8% of total biomass N.

Using the guidelines above to rank the silages in the present study, silages made from immature forages harvested from plots cut three times per season should be considered the lowest in terms of fermentation quality due mainly to the elevated acetic acid levels and the higher pH values that were recorded, particularly with those silages made from L79-1002 energycane and Mott dwarf elephantgrass. The silages made from full-season growth are the highest in fermentation quality while those made from plants harvested two times per season could be considered intermediate. It should be noted that silage quality expressed in terms of animal performance or methane yield may result in different "quality" rankings.

The Flieg point system modified by Zimmer and outlined by Woolford (1984) is a scoring procedure that is used for the quality indexing of silages. Scores range from zero to 100 where the latter number is the most desirable. Scoring is based on the relative proportions of acetic, butyric, and lactic acids to the total sum of these acids contained in a silage. More points are awarded to a silage when lactic acid, expressed as a percentage of total acids,

makes up the larger portion whereas fewer points are given when acetic and butyric acids make up the larger portions of total acids.

In the present study, the mean lactic acid portions of total acids during both seasons varied from 69 to 90% in PI 300086 and Merkeron elephantgrass silages for all harvest treatments (Tables 22 and 23). The energycane L79-1002 and Mott elephantgrass silages made from full-season growth also had high lactic acid percentages. However, with multiple harvests, lactic acid made up smaller portions due to the relative increase of acetic acid. From the same tables, the mean acetic acid percentages of total acids can be closely approximated by subtracting the mean lactic acid percentages from 100, since butyric acid contents in silages were negligible. Furthermore, the statistical results shown in Tables 22 and 23 were the same for acetic acid percentages. Overall, there was a tendency for the mean lactic acid percentages to decrease with more frequent harvesting. Conversely, the acetic acid percentages tended to increase.

Average Flieg scores for PI 300086 and Merkeron silages over all harvest treatments ranged from 84 to 100 (Tables 24 and 25). According to the Flieg index system, these scores denote very high silage quality. Lower scores were associated with silages made from immature L79-1002 energycane and Mott elephantgrass forages. The lowest mean score of 51, however, reflects average quality.

From a strict quantitative standpoint, one of the best indicators of the effectiveness of the ensilage process on the preservation of biomass is DM recovery. During both seasons, average DM recoveries for all

Table 22. Lactic acid percentage of total acids in elephantgrass and energycane silages made from plants grown under one, two, and three harvests in 1986 at Green Acres research farm near Gainesville, FL.

Genotype	F-test[¶]	Lactic acid		
		Harvests in 1986		
		1	2	3
		———— % of total acids[‡] ————		
PI 300086		88a[§]	90a	72a
Merkeron		89a	81a	69a
L79-1002[†]	L** Q**	88a	81a	21b
Mott		82	69	53

[†]Energycane (Saccharum spp.).

[‡]Total acids include acetic, butyric, and lactic acids.

[§]Means in the same column followed by the same letter are not different at the 5% level according to DMRT.

[¶]Linear (L) and/or quadratic (Q) effects are significant over harvest treatments, $P<0.01$ (**) or $P<0.05$ (*).

Table 23. Lactic acid percentage of total acids in elephantgrass and energycane silages made from plants grown under one, two, and three harvests in 1987 at Green Acres research farm near Gainesville, FL.

Genotype	F-test[¶]	Lactic acid		
		Harvests in 1987		
		1	2	3
		% of total acids[‡]		
PI 300086		86a[§]	78ab	88a
Merkeron	L**	87a	84a	77ab
L79-1002[†]		78b	56b	62b
Mott	L** Q*	89	59	47

[†]Energycane (Saccharum spp.).

[‡]Total acids include acetic, butyric, and lactic acids.

[§]Means in the same column followed by the same letter are not different at the 5% level according to DMRT.

[¶]Linear (L) and/or quadratic (Q) effects are significant over harvest treatments, $P < 0.01$ (**) or $P < 0.05$ (*).

Table 24. Flieg score of elephantgrass and energycane silages made
from plants grown under one, two, and three harvests in
1986 at Green Acres research farm near Gainesville, Fl.

Genotype	F-test[¶]	Total Flieg points		
		Harvests in 1986		
		1	2	3
PI 300086		99a[§]	100a	87a
Merkeron		100a	96a	84a
L79-1002 [†]	L** Q**	100a	97a	51b
Mott		84	84	65

[†]Energycane (Saccharum spp.).

[§]Means in the same column followed by the same letter are not
different at the 5% level according to DMRT.

[¶]Linear (L) and/or quadratic (Q) effects are significant over harvest
treatments, P<0.01 (**) or P<0.05 (*).

Table 25. Flieg score of elephantgrass and energycane silages made from plants grown under one, two, and three harvests in 1987 at Green Acres research farm near Gainesville, FL.

Genotype	F-test[¶]	Total Flieg points		
		Harvests in 1987		
		1	2	3
PI 300086		99a[§]	93a	100a
Merkeron		99ab	97a	94ab
L79-1002[†]		94b	69b	76b
Mott	L** Q**	100	70	63

[†]Energycane (Saccharum spp.).

[§]Means in the same column followed by the same letter are not different at the 5% level according to DMRT.

[¶]Linear (L) and/or quadratic (Q) effects are significant over harvest treatments, P<0.01 (**) or P<0.05 (*).

treatment combinations ranged from 84 to 98% (Tables 26 and 27).
Although some linear effects did appear, it is still unclear how DM
recovery is affected by harvest frequency. It is interesting to note
that with an ensiling method similar to the one used in the present
study, Brown and Chavalimu (1985) reported a 96% DM recovery for
elephantgrass harvested at 5 weeks of age.

Utilization of Elephantgrass Silage

At this point it is reasonable to conclude that elephantgrass at
various stages of plant maturity can be successfully stored for
prolonged periods using the ensilage process. However, further
investigation is needed to determine the types of silages that can be
most efficiently transformed into commercial products such as meat,
milk, and biogas.

In ruminant nutrition, animal performance is a function of
voluntary intake and digestibility of the forage being fed (Moore and
Mott, 1973). In the present study, the ensiling of elephantgrass and
energycane did not result in major changes in the original IVOMDs
shown in Tables 5 and 6 of Chapter Two. The mean percentage point
differences during 1986-87 between IVOMDs before and after ensiling
(Silage IVOMD - Original IVOMD = Difference) ranged from -9.4 to +4.2
(Table 28). The overall mean difference for all treatment
combinations during both years was -1.6. It should be noted that the
IVOMD values recorded for ensiled plant materials (not shown) may have
been slightly underestimated due to the losses of volatile substances
during the oven-drying of samples. The Moore and Mott (1974) IVOMD

Table 26. Dry matter recovery of elephantgrass and energycane forages that were stored by ensiling in 1986 at Green Acres research farm near Gainesville, FL.

Genotype	F-test[¶]	Dry matter recovery			
		Harvests in 1986			Average[§]
		1	2	3	
		%			
PI 300086		88	90	89	89a
Merkeron		91	89	87	89a
L79-1002[†]		<u>91</u>	<u>87</u>	<u>88</u>	89a
Overall average		90	89	88	
Mott	L**	94	87	86	89

[†]Energycane (<u>Saccharum</u> spp.).

[§]Means in the same column followed by the same letter are not different at the 5% level according to DMRT.

[¶]Linear (L) and/or quadratic (Q) effects are significant over harvest treatments, $P < 0.01$ (**) or $P < 0.05$ (*).

Table 27. Dry matter recovery of elephantgrass and energycane forages
that were stored by ensiling in 1987 at Green Acres
research farm near Gainesville, FL.

Genotype	F-test[¶]	Dry matter recovery			
		Harvests in 1987			Average[§]
		1	2	3	
		%			
PI 300086		91	93	96	94a
Merkeron		92	92	93	92a
L79-1002[†]		<u>84</u>	<u>89</u>	<u>92</u>	89b
Overall average	L**	89	91	94	
Mott		98	92	94	95

[†]Energycane (<u>Saccharum</u> spp.).

[§]Means in the same column followed by the same letter are not
different at the 5% level according to DMRT.

[¶]Linear (L) and/or quadratic (Q) effects are significant over harvest
treatments, P<0.01 (**) or P<0.05 (*).

Table 28. Mean percentage point difference between _in vitro_ organic matter digestibilities before and after the ensiling of elephantgrass and energycane which were gathered from plots harvested one, two, and three times per year at the Green Acres research farm near Gainesville, FL, during 1986–87.

		IVOMD difference		
		Harvests yr^{-1}		
Genotype	Year	1	2	3
			%	
PI 300086	1986	2.6[§]	-1.6	-0.4
Merkeron	1986	-0.9	-3.2	-1.3
L79-1002[†]	1986	0.5	-5.9*	-1.9
Mott	1986	-0.4	-3.8*	1.3
PI 300086	1987	-4.6	-2.8	2.2**
Merkeron	1987	-4.3	-5.2	1.3*
L79-1002	1987	-9.4*	-5.7*	-1.5
Mott	1987	2.7*	-0.2	4.2*

[†]Energycane (_Saccharum_ spp.).

[§]Differences were computed as follows: Silage IVOMD – Original IVOMD = Difference.

*,**Original forage and corresponding silage IVOMDs were significantly different at the 5 and 1% levels, respectively, according to the F-test.

procedure used for determinations involved 105°C oven-drying of previously dried samples (at 60°C) for 15 hours. Nevertheless, the data clearly demonstrate that ensiling is not a major factor affecting IVOMD. Therefore, the major factors affecting silage IVOMD would be the same as those affecting the IVOMD of original biomass such as harvest frequency and genotype. Working with sheep, Demarquilly (1973) observed similar results. Mean percentage point differences in apparent organic matter digestibility (corrected for volatile losses) between initial forages of several plant species and their corresponding silages ranged from -12.8 to +3.0. He concluded that the digestibility of ensiled material is mainly dependent on that of the original plant herbage at the time of harvest.

Many studies have shown the voluntary intake of silage to be lower than that of the original forage prior to ensiling (Wilkinson et al., 1976). The magnitudes of these reductions can be highly variable. Working with sheep, Demarquilly (1973) reported reductions in voluntary intake of silages that were made from several forage species, ranging from one to 64% when compared to the intakes of the original standing forages. The greater reductions in intake were attributed to silages with higher levels of volatile fatty acids, particularly acetic acid. The lesser reductions were related to silages that contained mostly lactic acid as the end-product of fermentation. Wilkins et al. (1971) also showed that the voluntary intake of sheep was negatively correlated with acetic acid contents in silages made from several forage species. Furthermore, their results showed that silage Flieg scores and intake were positively correlated.

In the present study, the silages containing the higher levels of acetic acid such as those made from immature Mott dwarf elephantgrass are the most likely to have problems with reduced voluntary intake.

In the literature, daily voluntary intakes of elephantgrass silage have been variable. In Cuba, Michelena et al. (1979) fed elephantgrass silage ad libitum plus minerals over a 160- to 180-day period to holstein x zebu bulls averaging 247 kg in liveweight. The silage contained 26% DM and a crude protein content of 4.8% (dry basis). Mean daily consumption of DM was 2.4% of liveweight. In Brazil, Vilela et al. (1983) fed elephantgrass silage to holstein x Zebu heifers averaging 258 kg in liveweight. The silage was made from 9- to 10-week old forage and contained 21% DM and 4.4% crude protein (dry basis). Average daily consumption of DM was estimated to be 2.7% of liveweight.

On the negative side, Cunha and Silva (1977) reported that elephantgrass silage (ensiled with 3% molasses) fed alone during the dry period in Brazil was inadequate for maintaining acceptable production of cows just prior to and after calving. Silage composition was 21% DM, 54% total digestible nutrients, and 8.1% crude protein (dry basis). The ad libitum feeding of the silage plus salt and minerals resulted in excessive postpartum weight loss of the cows, poor calf development, and a reduced rebreeding percentage when compared to a pasture feeding system. The poor performance was attributed to inadequate daily DM consumption. The average daily intake of DM was only 5.8 kg. The mean initial weight of the cows was 507 kg. In India, Nooruddiu and Roy (1975) fed elephantgrass silage

<u>ad</u> <u>libitum</u> plus salt to mature steers averaging 237 kg in liveweight.
The estimated contents of crude protein and total digestible nutrients
in the silage were 5.1 and 46% (dry basis), respectively. Mean daily
DM intake over an 18-day period was 1.3% of liveweight.

In a methane production system, the loading rate of biomass is
not under the voluntary control of anaerobic digesters. It can be
controlled and adjusted by the operator to optimize conversion rates
depending on the given circumstances. Therefore, loading rate should
not be a potential limiting factor as voluntary intake is in livestock
feeding systems. Furthermore, high levels of acetic acid in silage
which limits voluntary intake in ruminants, should not be a problem in
anaerobic methane digestion, since it is a major substrate used by
methanogenic bacteria (Gottschalk, 1979). However, if acetic acid is
the major end-product of the ensilage process, the quality of
preservation could be reduced because it is a weaker acid compared to
lactic acid. This would increase the chances of substantial DM losses
during a prolonged storage period.

The DM losses that occur during normal ensiling fermentations may
not greatly reduce the potential methane production per unit of land
area that is expected from a system where the biomass after harvesting
is immediately placed in a methane digester. The gross energy content
is as much as 10% greater per unit dry matter in silage than in the
initial biomass before ensiling (Woolford, 1984). In the present
study, methane yields per kg of volatile solid from a limited number
of samples, have been higher for elephantgrass silage than those of
original fresh biomass. Average methane yields for fresh PI 300096

elephantgrass gathered during the first cutting within the three harvest yr^{-1} treatment during 1986 and 1987 were 0.28 and 0.29 std m^3 kg^{-1} VS, respectively. Average yields from the corresponding silages were 0.33 and 0.33 std m^3, respectively. The methane yields of silage samples may, however, be inflated due to problems associated with the estimation of DM content of silage. At the Bioprocess Engineering Research Laboratory where the bioassays were conducted, an 105°C oven temperature was used for drying silage samples. At that temperature significant losses of volatile substances may have occurred during drying. Further detailed investigations are needed to determine if ensiling biomass improves methane yield.

Conclusions

Elephantgrass and energycane grown under one, two, and three harvests per season can be successfully stored for prolonged periods through the process of ensilage fermentation and without the use of additives. The success of ensiling these erect bunchgrasses in the present study is associated with a combination of desirable characteristics of the original fresh biomass. The fresh chopped plant materials apparently contained adequate levels of water soluble carbohydrates that provided energy for fermentation bacteria to proliferate. In addition, the initial forages possessed low buffering capacities (low resistances to pH changes). This combination of attributes of the freshly harvested herbage helps to explain the ease with which these grasses were ensiled.

Lactic acid was the primary end-product of fermentation in silages made from the tall elephantgrass genotypes PI 300086 and Merkeron under all harvest frequencies and from the full-season growth of L79-1002 energycane and Mott dwarf elephantgrass. However, with silages made from immature plants of L79-1002 and Mott, analysis showed that lactic and acetic acids were both major end-components of silage fermentation. The elevated acetic acid levels in Mott silages may negatively affect voluntary intake of ruminants. In a methane energy production system acetic acid being a major end-product of fermentation, should not affect methane yields per volatile solid of silage, but could reduce the preservation quality of the biomass, leading to greater chances of losing substantial amounts of DM during a prolonged storage period.

From a strict quantitative standpoint, the forages produced during the present study were effectively stored using the ensilage process. However, further investigations are needed to determine from an ultimate production standpoint, whether elephantgrass and energycane can be stored as silage and then efficiently converted into meat, milk, or energy products.

CHAPTER 4
GENERAL SUMMARY AND CONCLUSIONS

Elephantgrass is a perennial erect-growing bunchgrass indigenous to the wet equatorial areas in Africa. Recently, interests in this plant species have increased in several agricultural disciplines. Highly productive "tall" genotypes can be utilized as a biomass crop for energy or a soilage crop for ruminants such as dairy and beef cattle. For grazing animals, "dwarf" genotypes have been shown to be of high forage quality and are persistent under moderate grazing conditions.

In a 2-year study conducted on a dry, infertile site and under the subtropical conditions near Gainesville, the response of elephantgrass to three harvest frequencies was measured. Genotypes evaluated were four "tall" elephantgrasses (PI 300086, Merkeron, N-43, and N-51), a "dwarf" elephantgrass ('Mott'), a "semi-dwarf" Pennisetum glaucum (L.) R. Br. x P. purpureum Schum. hybrid (Selection No. 3) and a "tall" Saccharum species of energycane (L79-1002). To determine if these grasses could be stored as silage, the fresh chopped plant materials of PI 300086, Merkeron, Mott, and L79-1002 were hand-packed into 20-liter plastic containers lined with two 4-mil plastic bags.

Average dry biomass yields for the four tall elephantgrasses during the 1986-87 growing seasons were 27, 24, and 18 Mg ha^{-1} yr^{-1} for one, two, and three harvests per season, respectively. In vitro organic matter digestibilities were 40, 49, and 55%, while crude

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protein contents were 4.0, 5.8, and 7.9% (dry basis), respectively. Two-year averages for ash-free neutral detergent fiber were 81, 76, and 74% (dry basis).

Oven dry biomass yields for L79-1002 energycane were inferior to the tall elephantgrasses during 1986 but did not differ the following season. Energycane yields declined with more frequent harvesting.

For the dwarf elephantgrass Mott, 2-year average dry biomass yields were 13, 12, and 11 Mg ha^{-1} yr^{-1} for one, two, and three harvests per season, respectively. In vitro organic matter digestibilities were 40, 54, and 57%, while crude protein contents were 5.3, 7.1, and 9.6%, respectively. Two-year means for neutral detergent fiber were 77, 73, and 70%.

Elephantgrass genotypes Merkeron, N-43, N-51, and Mott and L79-1002 energycane survived the experimental conditions. The genotype PI 300086 was susceptible to winterkill, particularly when harvested multiple times per season. An almost complete loss of stand occurred in Selection No. 3 plots during the 2-year study.

Predicted methane production ha^{-1} for PI 300086 elephantgrass was similar for the three harvest treatments, although the highest values were recorded from two harvests per season.

Mean pH values ranged from 3.8 to 4.0 for the tall elephantgrass silages made from plants harvested at the different frequencies. The highest pH values were obtained from silages made from immature Mott plants harvested three times yr^{-1} (2-year mean was 4.3). Water soluble carbohydrate contents of fresh elephantgrass forages (range: 2.6 to 8.4%, dry basis) tended to increase with more frequent

harvesting. Buffering capacities of fresh PI 300086 and L79-1002 biomass were exceptionally low and also increased with more frequent harvesting. Mean buffering capacities were less than 150 meq NaOH kg^{-1} DM. Dry matter contents of fresh biomass decreased with more frequent harvesting for all genotypes during both growing seasons. Lactic acid was the major end-product of fermentation in most silages with the exception of those made from immature Mott elephantgrass and L79-1002 energycane plants where lactic and acetic acids were both major components. Average lactic acid contents during both seasons ranged from 1.4 to 5.3% (dry basis) for the elephantgrasses whereas mean acetic acid levels ranged from 0.25 to 2.21% (dry basis). Acetic acid contents in silages tended to increase when original plant materials before ensiling were more immature and succulent as compared to more mature materials. Butyric acid levels were negligible in all silages. Mean ammoniacal N percentages of total N in PI 300086 and L79-1002 silages ranged from 7.7 to 11.0. Dry matter recoveries for all silages ranged from 84 to 98%. The _in vitro_ organic matter digestibility of silage was mainly dependent on the IVOMD of the standing forages before ensiling.

The results of this study suggest the following general conclusions:

(1) Substantial biomass yields of elephantgrass can be produced without irrigation on dry, infertile sites and under the colder subtropical climate of North Central Florida.

(2) For the four tall elephantgrasses and L79-1002 energycane, as the number of harvests per growing season increases, the dry

biomass yields decline. With Mott dwarf elephantgrass, biomass yields are less affected by the harvest frequencies included in this study.

(3) For tall and dwarf elephantgrasses, forage crude protein contents and IVOMDs increase as the number of harvests per growing season increases. Neutral detergent fiber concentrations gradually decrease; however, major reductions do not occur.

(4) Variation in survival tolerance to increased harvest frequency and the subtropical conditions near Gainesville exists among genotypes. Elephantgrass genotypes Merkeron, N-43, N-51, and Mott and L79-1002 energycane could be recommended for planting in the area while PI 300086 and Selection No. 3 are not suitable.

(5) Elephantgrass and energycane grown under one, two, and three harvests per growing season can be successfully stored for prolonged periods through the ensiling process and without the use of additives.

(6) The ease with which the elephantgrasses and energycane were ensiled can be attributed to adequate levels of water soluble carbohydrates and the inherently low buffering capacities in the standing forages at the time of harvest.

The data show that many of the forages and silages produced in this study are potential sources of feedstocks that could be converted into animal and energy products. However, before other definite conclusions can be made, further investigations involving the actual components of conversion systems are needed (i.e., involving animals and anaerobic digesters). If problems do exist in a system such as inadequate animal intake or insufficient net energy production, for example, then it is likely they can be identified.

APPENDIX

Table 29. Oven dry biomass yield of elephantgrass genotypes from single harvests within multiple harvest treatments made during 1986 at Green Acres research farm near Gainesville, FL.

Genotype	Oven dry biomass yield				
	Harvests in 1986[§]				
	2		3		
	1st	2nd	1st	2nd	3rd
	$Mg\ ha^{-1}$				
PI 300086	15.51	14.21	7.19	8.25	6.32
Merkeron	15.57	12.10	7.68	8.51	5.19
N-43	15.27	12.05	6.64	7.90	4.62
N-51	15.51	12.04	5.67	7.30	5.01
L79-1002[†]	9.06	9.61	3.71	6.90	3.70
Selection No. 3[‡]	9.02	8.67	3.91	5.54	2.46
Mott	8.20	6.56	3.96	5.14	2.66

[†]Energycane (Saccharum spp.).

[‡]Pearlmillet x elephantgrass hybrid.

[§]For oven dry biomass yield of full-season growth refer to Table 1.

Table 30. Oven dry biomass yield of elephantgrass genotypes from single harvests within multiple harvest treatments made during 1987 at Green Acres research farm near Gainesville, FL.

	Oven dry biomass yield				
	Harvests in 1987[§]				
	2		3		
Genotype	1st	2nd	1st	2nd	3rd
	Mg ha^{-1}				
PI 300086	12.34	7.93	4.80	5.55	2.54
Merkeron	12.51	8.26	6.74	7.32	2.10
N-43	12.48	8.10	6.34	6.61	1.98
N-51	11.64	6.46	6.49	7.29	2.34
L79-1002[†]	9.37	8.50	4.16	7.07	2.44
Selection No. 3[‡]	2.93	1.14	3.40	2.63	0.19
Mott	5.83	3.39	4.51	4.46	0.79

[†]Energycane (Saccharum spp.).

[‡]Pearlmillet x elephantgrass hybrid.

[§]For oven dry biomass yield of full-season growth refer to Table 2.

Table 31. Crude protein content of elephantgrass genotypes from
single harvests within multiple harvest treatments made
during 1986 at Green Acres research farm near Gainesville,
FL.

	Crude protein				
	Harvests in 1986[§]				
	2		3		
Genotype	1st	2nd	1st	2nd	3rd
	%, dry basis				
PI 300086	6.02	5.20	6.87	9.39	7.46
Merkeron	5.98	4.70	6.86	9.25	8.08
N-43	8.18	5.59	7.23	9.18	7.37
N-51	5.44	5.11	7.29	9.31	8.03
L79-1002[†]	5.93	5.11	8.05	8.40	7.06
Selection No. 3[‡]	8.42	6.49	7.30	11.13	10.62
Mott	7.53	6.17	7.36	10.21	8.74

[†]Energycane (Saccharum spp.).

[‡]Pearlmillet x elephantgrass hybrid.

[§]For crude protein content of full-season growth refer to Table 3.

Table 32. Crude protein content of elephantgrass genotypes from single harvests within multiple harvest treatments made during 1987 at Green Acres research farm near Gainesville, FL.

Genotype	Crude protein				
	Harvests in 1987[§]				
	2		3		
	1st	2nd	1st	2nd	3rd
	%, dry basis				
PI 300086	5.66	6.52	5.79	6.40	10.37
Merkeron	5.62	6.20	5.94	6.25	10.39
N-43	4.84	6.26	7.06	6.78	11.27
N-51	4.94	6.34	6.35	6.61	10.27
L79-1002[†]	5.29	6.03	7.05	5.67	9.24
Selection No. 3[‡]	7.65	--	9.96	9.36	--
Mott	6.09	8.54	7.37	7.59	16.31

[†]Energycane (Saccharum spp.).

[‡]Pearlmillet x elephantgrass hybrid.

[§]For crude protein content of full-season growth refer to Table 4.

Table 33. In vitro organic matter digestibility (IVOMD) of
          elephantgrass genotypes from single harvests within
          multiple harvest treatments made during 1986 at Green Acres
          research farm near Gainesville, FL.

	IVOMD				
	Harvests in 1986[§]				
	2		3		
Genotype	1st	2nd	1st	2nd	3rd
	%				
PI 300086	46.2	48.2	55.6	55.5	53.8
Merkeron	48.5	49.6	58.5	56.9	51.7
N-43	52.5	50.9	58.8	57.2	52.7
N-51	49.4	48.9	57.7	56.1	54.1
L79-1002[†]	47.5	47.4	51.1	50.7	48.7
Selection No. 3[‡]	57.4	54.3	61.2	59.9	48.2
Mott	55.4	54.1	61.6	59.9	51.3

[†]Energycane (Saccharum spp.).

[‡]Pearlmillet x elephantgrass hybrid.

[§]For IVOMD of full-season growth refer to Table 5.

Table 34. In vitro organic matter digestibility (IVOMD) of elephantgrass genotypes from single harvests within multiple harvest treatments made during 1987 at Green Acres research farm near Gainesville, FL.

	IVOMD				
	Harvests in 1987[§]				
	2		3		
Genotype	1st	2nd	1st	2nd	3rd
	%				
PI 300086	50.8	43.6	58.1	49.5	54.0
Merkeron	53.7	46.8	59.6	53.1	50.9
N-43	51.3	46.3	59.7	54.1	52.3
N-51	51.2	42.9	59.5	52.8	52.5
L79-1002[†]	47.8	46.9	52.2	45.2	53.1
Selection No. 3[‡]	57.2	--	60.0	54.3	--
Mott	59.3	47.4	58.3	57.8	51.4

[†]Energycane (Saccharum spp.).

[‡]Pearlmillet x elephantgrass hybrid.

[§]For IVOMD of full-season growth refer to Table 6.

Table 35.   Ash-free neutral detergent fiber (NDF) content of
            elephantgrass genotypes from single harvests within
            multiple harvest treatments made during 1986 at Green Acres
            research farm near Gainesville, FL.

	NDF				
	Harvests in 1986[§]				
	2		3		
Genotype	1st	2nd	1st	2nd	3rd
	%, dry basis				
PI 300086	80.6	75.1	77.3	75.0	74.7
Merkeron	76.4	75.7	73.8	73.9	71.6
N-43	75.5	74.5	75.2	72.9	73.0
N-51	77.7	76.5	75.3	73.2	72.3
L79-1002[†]	78.0	77.5	76.0	77.2	77.9
Selection No. 3[‡]	71.3	72.7	68.6	68.0	67.4
Mott	73.0	73.4	69.8	71.0	68.5

[†]Energycane (<u>Saccharum</u> spp.).

[‡]Pearlmillet x elephantgrass hybrid.

[§]For NDF content of full-season growth refer to Table 7.

Table 36.   Ash-free neutral detergent fiber (NDF) content of
elephantgrass genotypes from single harvests within
multiple harvest treatments made during 1987 at Green Acres
research farm near Gainesville, FL.

	NDF				
	Harvests in 1987[§]				
	2		3		
Genotype	1st	2nd	1st	2nd	3rd
	%, dry basis				
PI 300086	76.5	78.5	74.9	80.4	73.6
Merkeron	74.8	76.1	73.6	77.4	73.5
N-43	76.2	74.8	72.0	77.0	73.2
N-51	76.7	78.0	73.1	77.1	72.2
L79-1002[†]	76.8	75.4	77.3	81.6	75.5
Selection No. 3[‡]	67.7	--	66.4	71.6	--
Mott	69.9	74.7	69.3	73.8	65.6

[†]Energycane (_Saccharum_ spp.).

[‡]Pearlmillet x elephantgrass hybrid.

[§]For NDF content of full-season growth refer to Table 8.

Table 37. Dry matter content of elephantgrass and energycane from
single harvests within multiple harvest treatments made
during 1986 at Green Acres research farm near Gainesville,
FL.

	Dry matter				
	Harvests in 1986[§]				
	2		3		
Genotype	1st	2nd	1st	2nd	3rd
	%				
PI 300086	22.7	29.5	17.5	18.8	20.6
Merkeron	21.3	29.5	16.5	19.0	24.6
L79-1002[†]	22.0	26.6	18.4	21.6	23.1
Mott	21.2	25.4	20.3	18.5	22.9

[†]Energycane (Saccharum spp.).

[§]For dry matter content of full-season growth refer to Table 11.

Table 38. Dry matter content of elephantgrass and energycane from single harvests within multiple harvest treatments made during 1987 at Green Acres research farm near Gainesville, FL.

	Dry matter				
	Harvests in 1987[§]				
	2		3		
Genotype	1st	2nd	1st	2nd	3rd
	— % —				
PI 300086	25.3	27.4	18.9	20.5	19.4
Merkeron	23.0	26.9	17.3	19.5	24.0
L79-1002[†]	21.8	28.3	20.3	20.2	26.3
Mott	20.0	28.0	19.1	20.0	35.4

[†]Energycane (Saccharum spp.).

[§]For dry matter content of full-season growth refer to Table 12.

Table 39. Water soluble carbohydrate (WSCHO) content of elephantgrass and energycane from single harvests within multiple harvest treatments made during 1987 at Green Acres research farm near Gainesville, FL.

	WSCHO				
	Harvests in 1987[§]				
	2		3		
Genotype	1st	2nd	1st	2nd	3rd
	%, dry basis				
PI 300086	10.64	6.09	10.43	10.88	3.16
Merkeron	9.12	5.98	10.28	10.38	2.92
L79-1002[†]	12.04	7.06	8.52	8.73	4.18
Mott	7.17	1.97	7.79	6.13	--

[†]Energycane (Saccharum spp.).

[§]For WSCHO content of full-season growth refer to Table 13.

Table 40. Buffering capacity of PI 300086 elephantgrass and L79-1002
energycane from single harvests within multiple harvest
treatments made during 1987 at Green Acres research farm
near Gainesville, FL.

Genotype	Buffering capacity				
	Harvests in 1987[§]				
	2		3		
	1st	2nd	1st	2nd	3rd
	Meq NaOH kg^{-1} DM[†]				
PI 300086	76.2	78.9	99.8	81.3	156.2
L79-1002	148.7	112.7	175.3	130.0	131.9

[†]Milliequivalents of NaOH required to raise the pH of one kg of
biomass DM from 4.0 to 6.0.

[§]For buffering capacity of full-season growth refer to Table 14.

Table 41. The pH of elephantgrass and energycane silages made with plants from single harvests within multiple harvest treatments during 1986 at Green Acres research farm near Gainesville, FL.

Genotype	Silage pH				
	Harvests in 1986[§]				
	2		3		
	1st	2nd	1st	2nd	3rd
PI 300086	3.91	3.81	3.92	4.03	3.92
Merkeron	3.91	3.86	3.97	4.02	4.14
L79-1002[†]	3.97	3.88	4.10	4.39	4.33
Mott	4.21	4.08	4.05	4.50	4.26

[†]Energycane (<u>Saccharum</u> spp.).

[§]For pH of silages made from full-season growth refer to Table 15.

Table 42. The pH of elephantgrass and energycane silages made with
plants from single harvests within multiple harvest
treatments during 1987 at Green Acres research farm near
Gainesville, FL.

	Silage pH				
	Harvests in 1987[§]				
	2		3		
Genotype	1st	2nd	1st	2nd	3rd
PI 300086	3.80	3.76	3.89	3.76	3.89
Merkeron	3.81	3.71	3.88	3.79	3.94
L79-1002[†]	4.17	3.83	4.11	4.06	3.95
Mott	4.23	4.27	4.33	4.42	--

[†]Energycane (Saccharum spp.).

[§]For pH of silages made from full-season growth refer to Table 16.

Table 43. Lactic acid content of elephantgrass and energycane silages made with plants from single harvests within multiple harvest treatments during 1986 at Green Acres research farm near Gainesville, FL.

Genotype	Lactic acid				
	Harvests in 1986[§]				
	2		3		
	1st	2nd	1st	2nd	3rd
	%, dry basis				
PI 300086	3.07	3.00	3.58	3.83	3.50
Merkeron	3.40	3.45	2.14	4.79	3.76
L79-1002[†]	2.30	3.30	1.07	0.03	0.89
Mott	2.74	3.93	2.63	0.33	4.23

[†]Energycane (Saccharum spp.).

[§]For lactic acid content of silages made from full-season growth refer to Table 17.

Table 44. Lactic acid content of elephantgrass and energycane silages made with plants from single harvests within multiple harvest treatments during 1987 at Green Acres research farm near Gainesville, FL.

Genotype	Lactic acid				
	Harvests in 1987[§]				
	2		3		
	1st	2nd	1st	2nd	3rd
	%, dry basis				
PI 300086	1.91	3.38	2.23	5.37	8.30
Merkeron	4.23	3.94	2.50	5.68	5.38
L79-1002[†]	0.68	3.74	1.58	2.86	4.56
Mott	2.55	3.81	1.44	2.57	--

[†]Energycane (Saccharum spp.).

[§]For lactic acid content of silages made from full-season growth refer to Table 18.

Table 45. Acetic acid content of elephantgrass and energycane silages
made with plants from single harvests within multiple
harvest treatments during 1986 at Green Acres research farm
near Gainesville, FL.

	Acetic acid				
	Harvests in 1986[§]				
	2		3		
Genotype	1st	2nd	1st	2nd	3rd
	%, dry basis				
PI 300086	0.37	0.28	1.44	0.62	0.76
Merkeron	1.05	0.44	2.53	1.33	0.88
L79-1002[†]	0.90	0.40	2.35	3.26	2.03
Mott	2.23	0.67	1.10	4.11	1.35

[†]Energycane (Saccharum spp.).

[§]For acetic acid content of silages made from full-season growth refer
to Table 19.

Table 46. Acetic acid content of elephantgrass and energycane silages made with plants from single harvests within multiple harvest treatments during 1987 at Green Acres research farm near Gainesville, FL.

	Acetic acid				
	Harvests in 1987[§]				
	2		3		
Genotype	1st	2nd	1st	2nd	3rd
	%, dry basis				
PI 300086 ·	1.15	0.31	0.30	0.42	1.34
Merkeron	0.92	0.62	1.44	1.19	1.32
L79-1002[†]	2.70	0.60	2.11	2.29	0.75
Mott	2.55	1.81	2.65	1.77	--

[†]Energycane (<u>Saccharum</u> spp.).

[§]For acetic acid content of silages made from full-season growth refer to Table 20.

Table 47. Ammoniacal N percentage of total N in PI 300086 elephantgrass and L79-1002 energycane silages made with plants from single harvests within multiple harvest treatments during 1987 at Green Acres research farm near Gainesville, FL.

	Ammoniacal N				
	Harvests in 1987[§]				
Genotype	2		3		
	1st	2nd	1st	2nd	3rd
	%				
PI 300086	10.57	10.44	9.59	9.26	9.90
L79-1002	7.72	7.62	9.24	9.85	6.74

[§]For ammoniacal N percentage of total N of silages made from full-season growth refer to Table 21.

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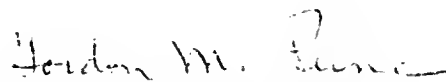SAS Institute, Inc. 1982. SAS user's guide: Statistics, 1982 edition. SAS Institute, Inc., Cary, NC, 584 pp.

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BIOGRAPHICAL SKETCH

Kenneth Robert Woodard was born on December 30, 1954, in
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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.
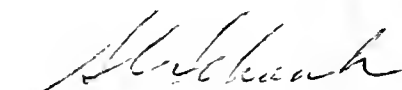
Gordon M. Prine, Chairman
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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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